NOVEMBER 1952

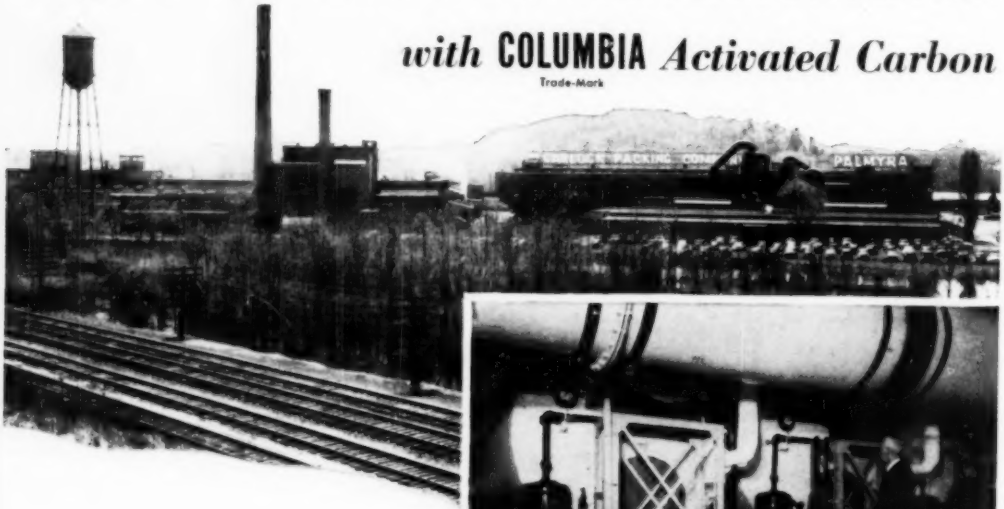
Chemical Engineering Progress

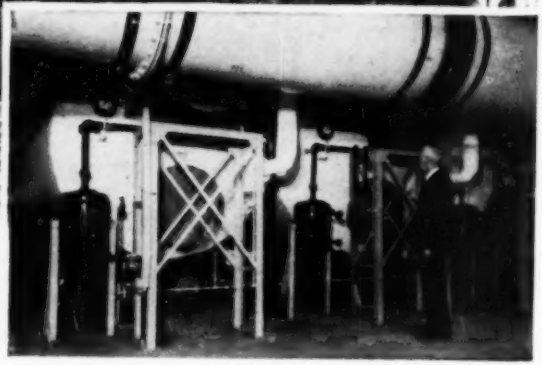
PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

95% of Gasoline Solvent Recovered

with COLUMBIA *Activated Carbon*

Trade-Mark





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Send for our 16-page booklet "How 7 Industries Save $150,000,000 a year with COLUMBIA Activated Carbon" which tells how other companies have profited. A request on your letterhead will bring you a copy, without obligation. Write today.

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A Division of
Union Carbide and Carbon Corporation
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COLUMBIA
Activated Carbon

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GAS AND AIR PURIFICATION

A modern solvent recovery plant for The Garlock Packing Company, Palmyra, New York, using COLUMBIA Activated Carbon as the adsorbent, collects about 1,000 pounds of gasoline vapor per hour from the air and delivers it ready for re-use. The gasoline is vaporized during the manufacture of asbestos sheet packing and is recovered at lower cost and higher efficiency than is possible with any other commercial method. Operating records for a 10-month period since the plant started show an *overall* recovery efficiency of 95.9 per cent. In addition to the profitable recovery of gasoline, this installation also:

- improves the working conditions in the plant,
- helps reduce the hazards of handling gasoline vapors,
- avoids the discharge of large volumes of solvent-laden air into the atmosphere.

The special features of CARBIDE'S automatic equipment and the high adsorptive capacity of COLUMBIA Activated Carbon make such performance possible for Garlock Packing.

If you vaporize solvents in your process, let CARBIDE help you conserve valuable solvents, improve processing conditions, and clean up exhaust air. We can supply you with a complete, automatic, instrument-controlled plant designed for your specific requirements with guaranteed operating efficiency to recover solvent vapors or purify industrial gases.

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Volume 48
Number 11

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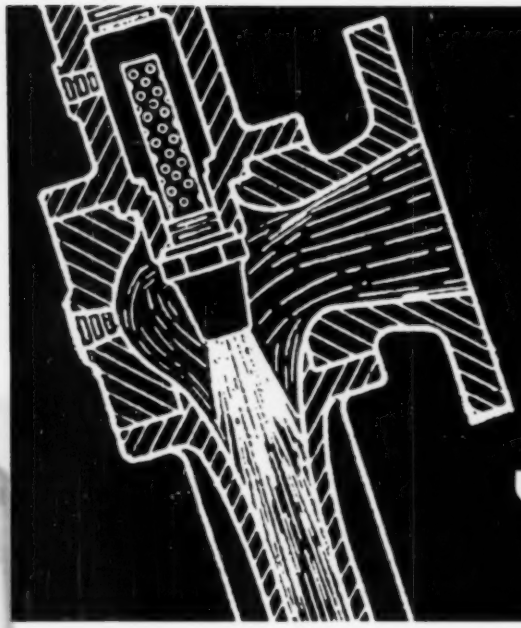

this evactor works for "nothing"

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Croll-Reynolds supplies Evactors in 1, 2, 3, 4 and 5-stage units, operating in the following pressure ranges:

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2-stage	0.5 to 4 inches of mercury absolute
3-stage	2 to 12 millimeters of mercury absolute
4-stage	0.15 to 3 millimeters of mercury absolute
5-stage	down to a few microns

The one and two stage units are used primarily to remove non-condensables, in priming and in vapor removal. Three-stage Evactors find application in the growing field of vacuum refrigeration, and in the chemical, food and petroleum industries. Four and five-stage units meet demanding vacuum requirements in many fields.

Many thousands of Croll-Reynolds Evactors are in operation, some of them for over 30 years. They are installed in every state of the United States and in many foreign countries. Let our technical staff help you with your vacuum problems.

INFORMATION NEEDED FOR QUOTATIONS

1. MINIMUM STEAM PRESSURE.
2. MAXIMUM TEMPERATURE OF CONDENSING WATER.
3. MINIMUM ABSOLUTE PRESSURE REQUIRED.
4. MAXIMUM DISCHARGE PRESSURE.
5. TYPE OF LOAD; THIS TO INCLUDE MOLECULAR WEIGHT OF GAS OR VAPORS OTHER THAN AIR AND PERCENTAGE OF EACH GAS OR VAPOR MAKING UP LOAD.
6. AMOUNT OF LOAD TO BE HANDLED PREFERABLY IN POUNDS PER HOUR.
7. TEMPERATURE OF LOAD.
8. TYPE OF CONDENSER DESIRED; BAROMETRIC OR SURFACE TYPE.
9. SPECIAL MATERIALS OF CONSTRUCTION NEEDED.

All of the above information is important for any EVACTOR with intercooler, precooler or aftercooler. Items 1, 3, 4, 5, 6, 7 and 9 are important for single stage and other non-condensing EVACTORS. Blank inquiry sheets are available on request, also literature.

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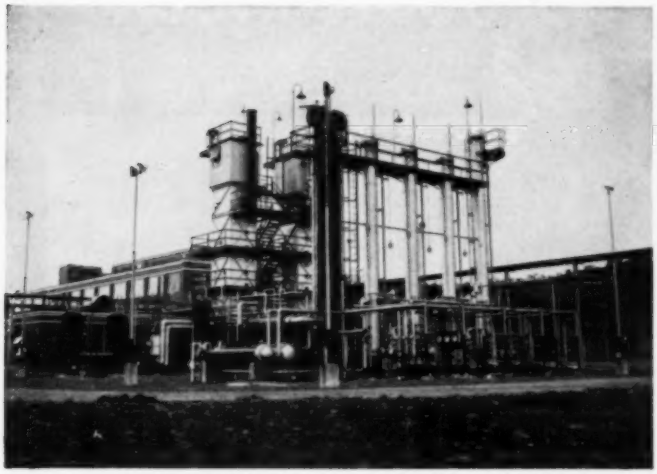
CHILL-VACTORS STEAM JET EVACTORS CONDENSING EQUIPMENT



Girdler HYGIRTOL Plant at U. S. Bureau of Mines Synthetic Liquid Fuels Plant . . . supplies both pure hydrogen and various mixtures of synthesis gas.*

Complete engineering-construction service assures a job "well done"

FOR PROCESS PLANTS in the chemical, natural gas, and petroleum industries, Girdler assumes unit responsibility for design, process engineering, and construction. This saves you engineering manhours and time. Most important, it assures proper coordination of the whole project and successful results.

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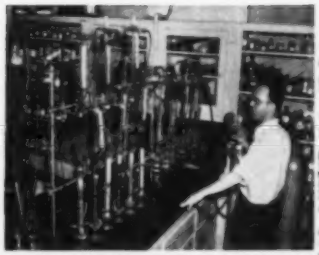
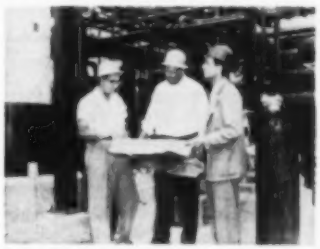


PROCESS RESEARCH—Girdler's research and development department is well equipped to assist with all types of process problems. A technical staff is available for consultation, and Girdler's research group can be employed on special problems at reasonable cost.

ENGINEERING—Experienced executives direct a group of engineering specialists, trained for every job requirement. In addition to basic process and equipment design, Girdler engineers have broad experience in buildings, foundations, electrical systems, boiler plants, instrumentation, etc.



ON-THE-JOB—Girdler engineers supervise and direct all phases of construction. When the job is completed, experienced operating engineers will start up the plant, train operating personnel, run acceptance tests, and supply complete operating data.

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Gas Processes Division

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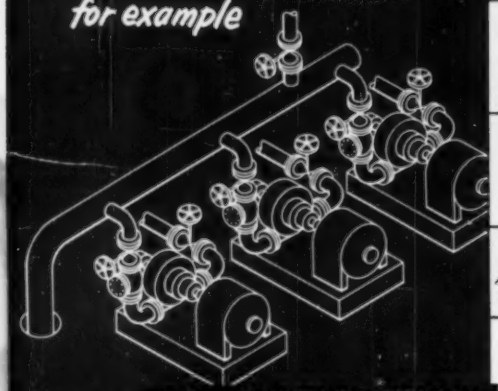
VOTATOR DIVISION: *Processing Apparatus for the Food and Chemical Industries*
THERMEX DIVISION: *Industrial High Frequency Dielectric Heating Apparatus*

Can You Trust Your Checks to Hold Like This?

. . . on Water Pumps, for example



THE INSTALLATION

Crane Iron Body Swing Check Valves in 8-inch vertical lines on discharge side of water pumps supplying a large eastern paper mill.

VALVE SERVICE RATINGS

SUITABILITY: Working smoothly - no complaints

FEATURES: O.K. for either horizontal or upward flow

MAINTENANCE COST: None - no maintenance needed to date

SERVICE LIFE: Now better than other checks used

OPERATING RESULTS: No water or head loss

PRICE: In line with other makes

AVAILABILITY: Stock item - Crane product

THE HISTORY

The mill depends on these pumps for all water. Loss of head at the pumps would create a serious problem. The mill could take no such risks. Regularly, the check valves on pumps were replaced, but only to be found leaking between pumping cycles, a few months later.

It's now more than a year since the change-over was made to Crane Check Valves. There's been no loss of water, no maintenance or replacement of any checks on the pumps. That was proof enough for the mill, that Crane Quality means better valves —greater dependability and bigger value. As a result, 3 more of these checks were installed on a separate battery of suction pumps.

THE VALVE

Crane No. 373, 125-Pound Iron Body Swing Check Valves, brass trimmed. The long life and high seating efficiency of these checks, in 2 to 8-in. sizes, is in large part due to the Crane patented flexible disc-hinge design. Double spring mounting eliminates lost motion between parts, yet permits true, full contact of disc and seat at every closure. Also serves to absorb the shock of seating under back-flow pressure. See your Crane Catalog or Crane Representative for full details.

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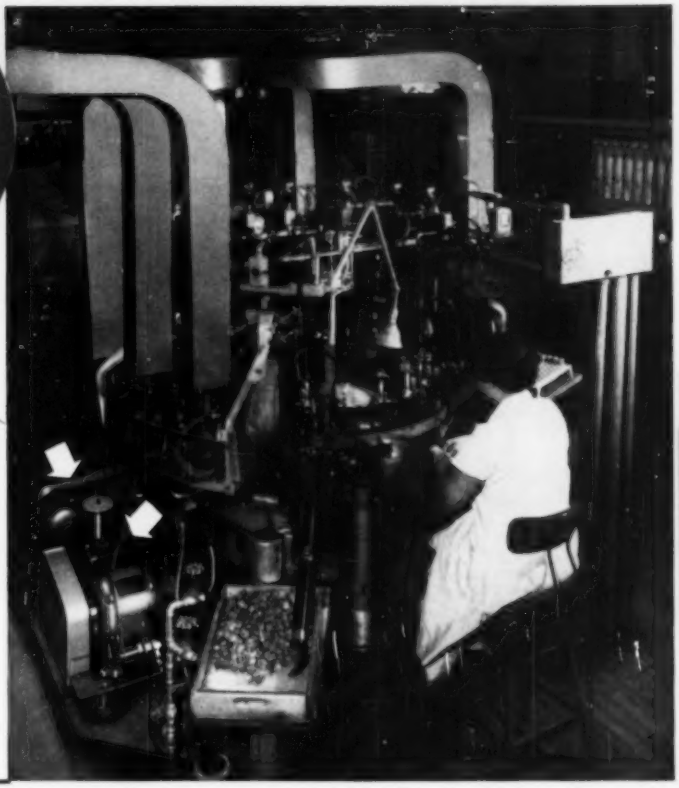
KINNEY HIGH VACUUM PUMPS



Electronic tubes for rural telephone circuits make two trips around this rotary sealing machine before they take the big trip to the country. First, the tubes receive their glass envelopes, after which they are evacuated and sealed under ultra-high vacuum . . . created by Kinney Vacuum Pumps.

To insure proper operation and long tube life, every trace of oxygen must be exhausted from the tubes before sealing. Kinney Vacuum Pumps are used in this and thousands of other automatic exhaust machines throughout the world. They combine these all-important features: fast recovery speed, low ultimate pressures, and complete dependability.

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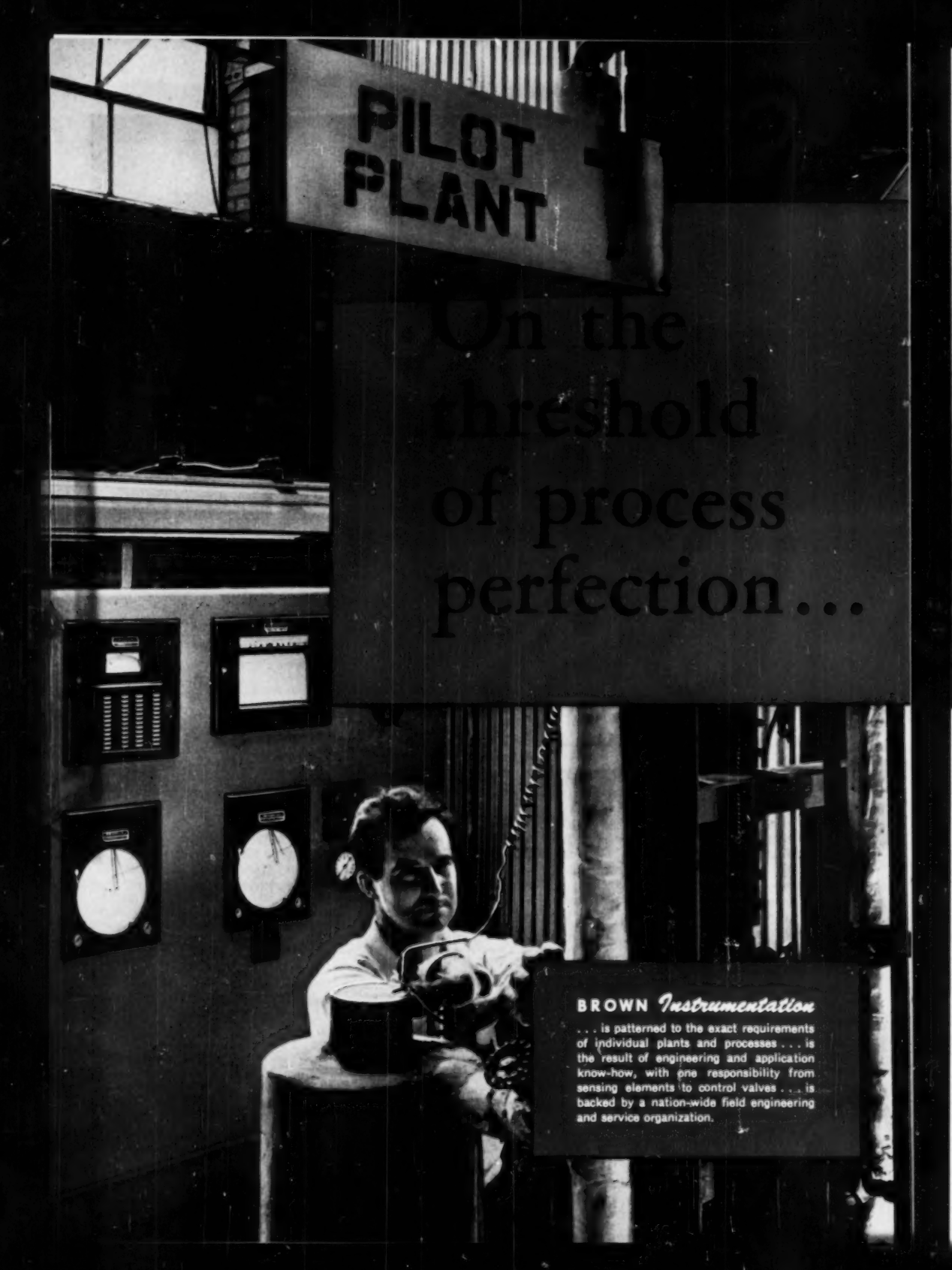
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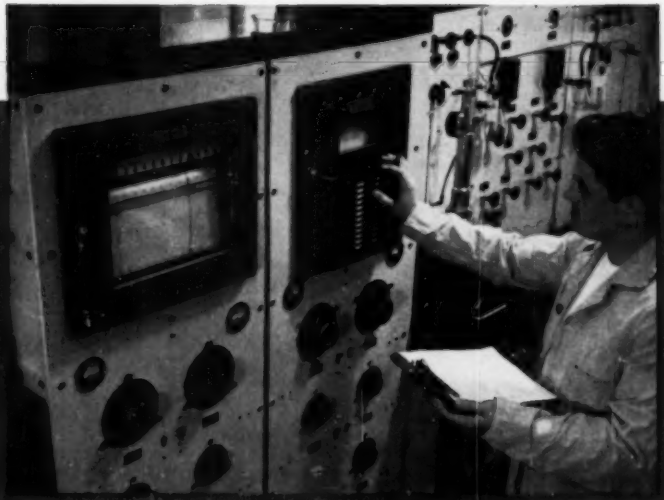
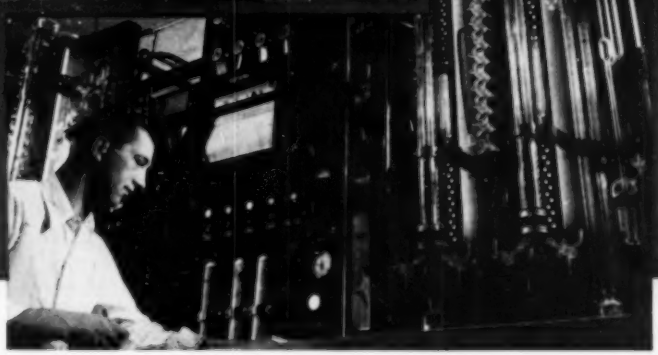
. . . is patterned to the exact requirements of individual plants and processes . . . is the result of engineering and application know-how, with one responsibility from sensing elements to control valves . . . is backed by a nation-wide field engineering and service organization.





PROVING processes in the pilot plant stage can save untold millions of dollars in "on-stream" operations. But bridging the gap between fluid ounces per hour in the laboratory and hundreds or thousands of barrels per hour in the plant takes considerable doing.

Thorough instrumentation in the pilot plant provides . . . (1) *a saving in scientific man-hours*, through the centralization of critical data which eliminates the hand logging of hundreds or even thousands of points . . . (2) *easy and rapid interpretation of data*, through automatic coordination and recording in chart form . . . and (3) *process simplification*, through a complete understanding of control problems well in advance of full-scale operations.

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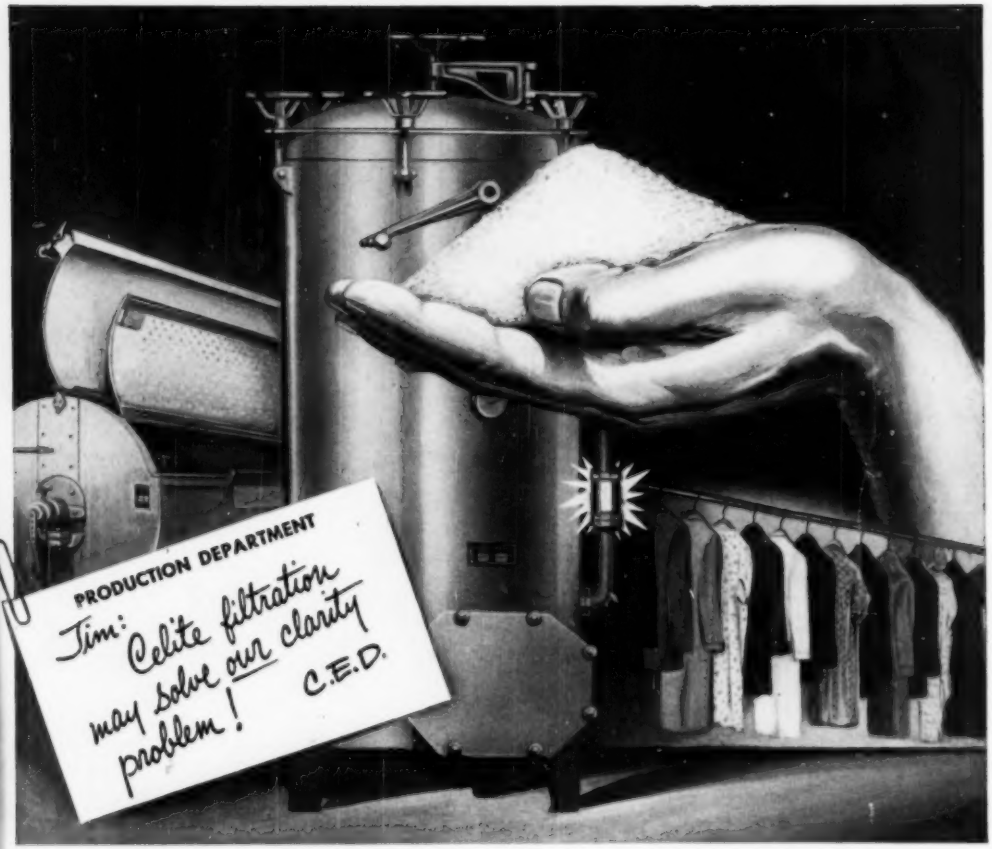

"Drycleaners' Rx" for filtering solvent crystal-clear

MODERN drycleaning plants have discovered that the prescription for keeping their cleaning fluid crystal-clear . . . *an absolute necessity if garments are to be thoroughly cleaned* . . . is Celite* filtration.

The effectiveness of Celite can be attributed to these important factors which make it unique among filter aids:

Carefully processed from the purest deposit of diatomaceous silica known, Celite is available in nine standard grades—each designed to trap suspended impurities of a given size and type. Whenever you reorder, you are assured of the same uniform, accurately graded powder received in your initial order. Thus, with Celite, you can count on consistent clarity and purity in your filtrates—at highest rate of flow—month after month, year after year.

Drycleaning solvent is just one of many liquids for which Celite has provided the absolute clarity vital to a successful operation. The proper grade of Johns-Manville filter aid will assure you the same results—regardless of the product or process involved. To have a Celite Filtration Engineer study your problem and offer recommendations, simply write Johns-Manville, Box 60, New York 16, New York. No cost or obligation.

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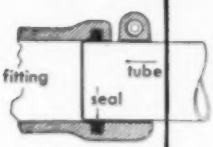

Designed to reduce assembly costs and to permit the use of less expensive lighter wall tubing. ***Quikupl*** stainless steel elbows, tees, couplings, reducers and adapters save you time, labor, materials and money.

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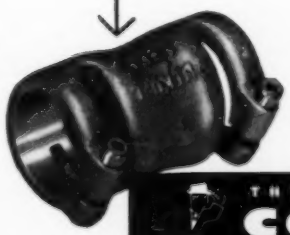

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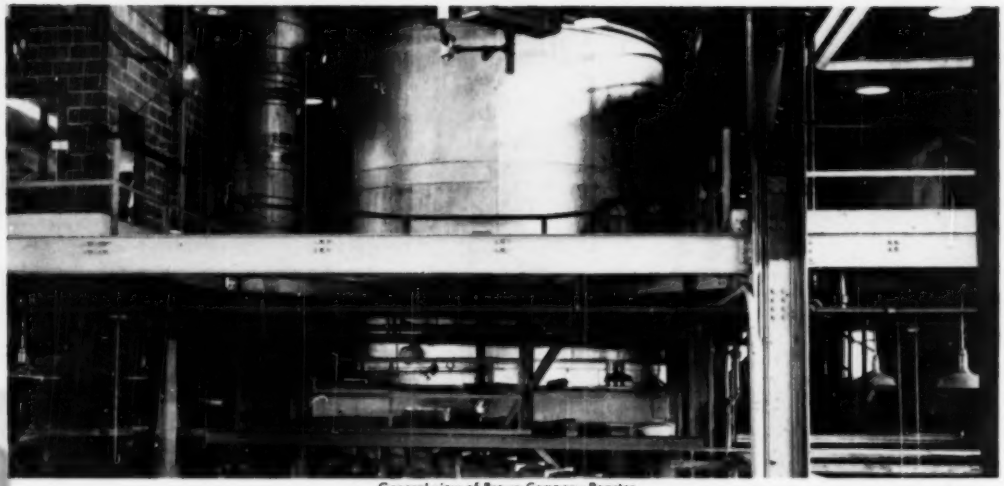
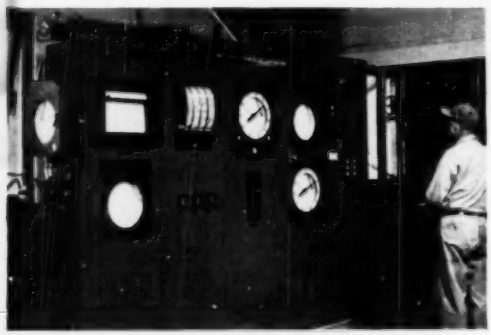


General view of Brown Company Reactor

First Dorrco FluoSolids* Reactor For Producing SO_2 Goes "On Stream" at Brown Company

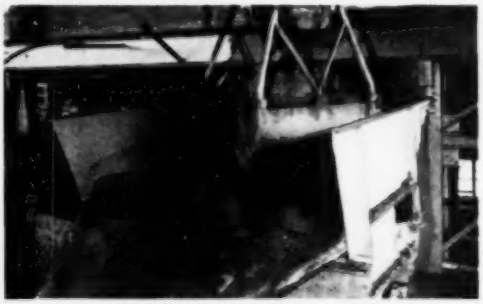
BERLIN, N. H. In anticipation of a continuing sulfur shortage, The Brown Company at Berlin, N. H. recently installed a Dorrco FluoSolids System to produce SO_2 gas from pyrrhotite. The System at the present time is supplying the entire sulfur requirements of this sulfite pulp mill . . . 11,000 tons of sulfur equivalent per year. A producer of quality pulp for high-grade photographic papers, Brown requires clean, high-strength SO_2 gas to make their sodium sulfite cooking liquor.



Centralized control panel

RAW MATERIAL FORMERLY A WASTE PRODUCT

The pyrrhotite, recovered from tailings of a nearby copper mine, is received in a moist condition, repulped with water to 70-75% solids, and pumped into the Reactor. By operating close to theoretical oxygen requirements, the strongest possible SO_2 gas is produced, with a black magnetite calcine which is quenched and handled in slurry form. Roast is accomplished in a 16' inside diameter Reactor with the temperature automatically held at 1650°F.



Clamshell discharging pyrrhotite into blunger

HIGH STRENGTH SO_2 PRODUCED

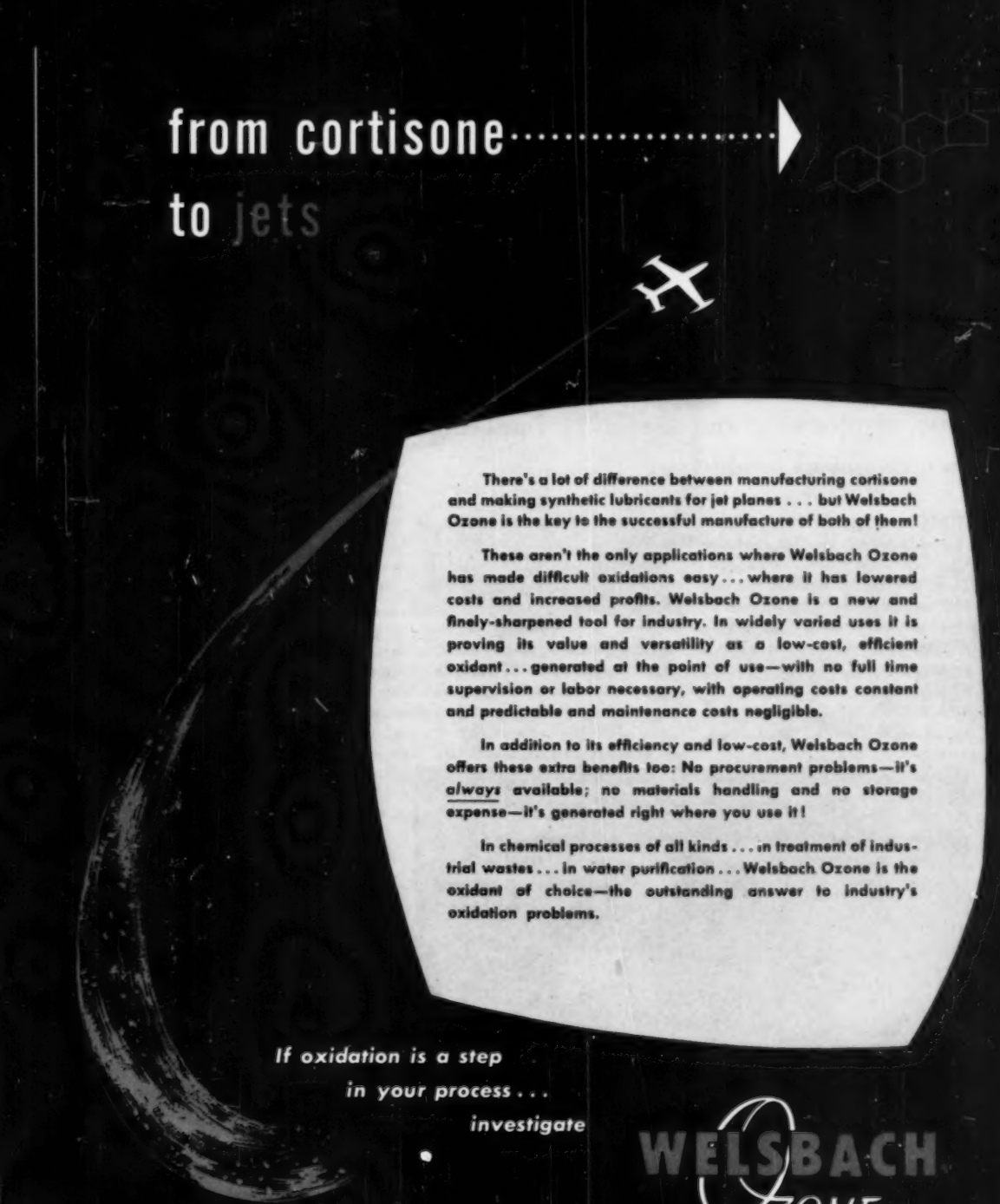
Gas strength at the top of the Reactor averages 13% SO_2. The gas then passes through a two-stage cyclone system followed by a cooling-scrubbing tower before going to the acid towers. Average chemical analysis of feed and calcine follows:

	Total Sulfur	Sulfide Sulfur	Total Fe
Pyrrhotite Feed	35.7	35.6	49.1
Combined Calcine	0.51	0.49	60.9

For detailed information about Fluo-Solids — a distinct departure from conventional roasters — write for Bulletin No. 7500. The Dorr Company, Stamford, Conn. or in Canada, The Dorr Company, 80 Richmond Street West, Toronto 1.

* Trademark Reg. U. S. Pat. Off.

from cortisone ..... to jets



There's a lot of difference between manufacturing cortisone and making synthetic lubricants for jet planes . . . but Welsbach Ozone is the key to the successful manufacture of both of them!

These aren't the only applications where Welsbach Ozone has made difficult oxidations easy . . . where it has lowered costs and increased profits. Welsbach Ozone is a new and finely-sharpened tool for industry. In widely varied uses it is proving its value and versatility as a low-cost, efficient oxidant . . . generated at the point of use—with no full time supervision or labor necessary, with operating costs constant and predictable and maintenance costs negligible.

In addition to its efficiency and low-cost, Welsbach Ozone offers these extra benefits too: No procurement problems—it's *always* available; no materials handling and no storage expense—it's generated right where you use it!

In chemical processes of all kinds . . . in treatment of industrial wastes . . . in water purification . . . Welsbach Ozone is the oxidant of choice—the outstanding answer to industry's oxidation problems.

If oxidation is a step in your process . . . investigate

WELSBACH OZONE

THE WELSBACH CORPORATION

1500 Walnut Street Philadelphia 2, Pa

PIONEERS IN CONTINUING OZONE RESEARCH

PYREX® brand "Double-Tough" glass pipe gives Berkeley Chemical Corporation* great processing flexibility

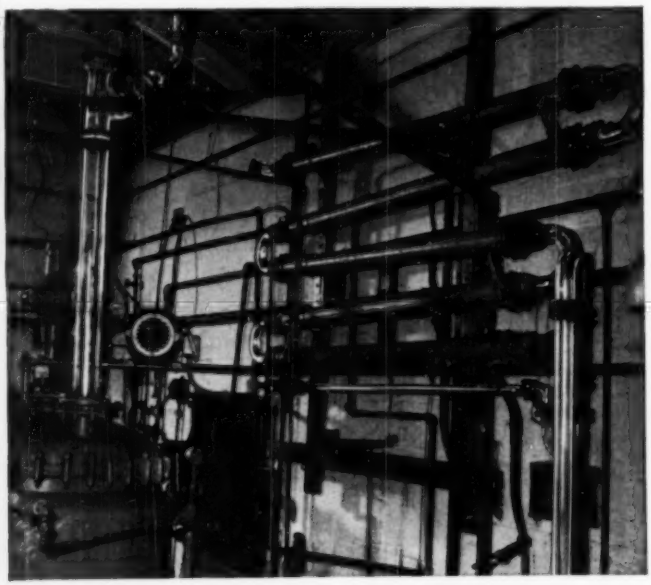
Corrosion resistance, visibility, ease of cleaning and assembly important to economical production

BECAUSE of the variety of chemical products handled, Berkeley Chemical Corp.,* Berkeley Heights, N. J., has long recognized the fact that only glass would withstand its more corrosive materials, provide the visibility necessary to check processes continuously, provide ease of cleaning, and make frequent rearrangements of condenser and gravity separator elements a simple matter.

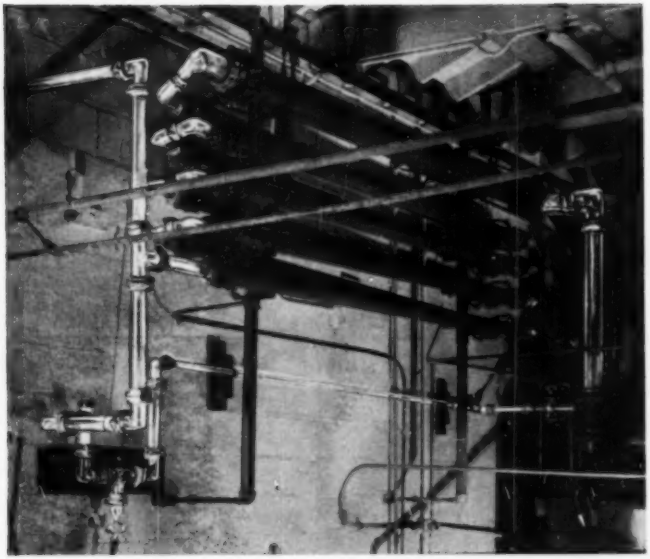
The raw materials handled include organic acids and three notorious corroding agents — iodine, chlorine, and bromine. Solvents used in the various processes include sulfuric and hydrochloric acids, benzene, toluene, chloroform, alcohol, xylene, acetone and, at the far end of the scale, a variety of caustics.

Dr. Sidney Beinfest, Vice President of Berkeley, says that "PYREX pipe and heat exchanger glass is not affected by anything the company has ever put through them. In fact, the use of glass makes practical the processing of any probable combination of chemicals in the pharmaceutical and intermediate fields. The effect of this single fact makes the company confidently willing to tackle anything within the reach of its sales organization — Millmaster Chemical Corp."

*An affiliate of Millmaster Chemical Corp.

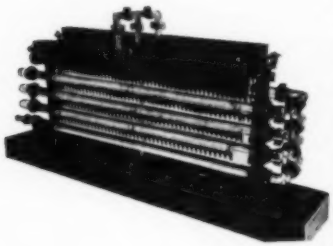


This picture shows a glass air condenser connected to the reaction kettle for an iodination process. Iodine which crystallizes on the wall of the vertical 4" glass tube is recovered and returned to the process. On the wall to the right is a specially designed jacketed PYREX water-cooled condenser made of 2" pipe and U-bends. Change over to the wet condenser can be made in 20 to 30 minutes. Mike Zelkind, Production Engineer, stated that most of the U-bends and all of the pipe in this condenser are over 5 years old. Mechanical failure has averaged one in two years, and that was due to lack of flexibility in the wall mounting.



The specially designed condenser shown in the top center of this picture includes a top run of 4" x 10' PYREX heat exchanger tubing, and 8 2-inch diameter PYREX tubes. Jackets are stock pieces of black iron pipe. Standard PYREX stuffing boxes make the seals. Note that instead of U-bends at the ends of the tubes, connections are formed of 2" PYREX 90° elbows to increase flexibility. Note also the loose-hung suspension system of this unit for protection against vibration. Gaskets are Teflon. To date the only maintenance has been occasional gasket replacement. Gasket replacement takes "less than 5 minutes."

PYREX brand Cascade Coolers . . . the efficient, economical way to cool corrosives



IN practically every application involving the cooling or condensing of corrosive liquids, standard PYREX brand cascade coolers will provide the efficient, economical solution. Exceptionally resistant to virtually all acids, they assure long service life and protect sensitive products. Further economies result from the use of low-cost river or sea water as a coolant.

Low in first cost per BTU transferred, they also cost less to clean and maintain. Unusual versatility of mounting on walls, floor and ceiling saves space. And you get maximum heat transfer through thin but sturdy walls.

The PYREX pipe distributors listed below carry the complete line

Contact the one nearest you:

BELMONT, CALIFORNIA
Glass Engineering Laboratories

FRESNO 17, CALIFORNIA
Valley Fdy. & Mach. Works

NEW HAVEN, CONNECTICUT
Macalaster Bicknell Company

ATLANTA, GEORGIA
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CHICAGO 44, ILLINOIS
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CORNING GLASS WORKS
Dept. EP-11, Corning, N. Y.

Please send me the printed information checked below:

- ☐ "PYREX brand Glass Pipe in the Process Industries" (EA-1)
- ☐ "PYREX brand "Double-Tough" Glass Pipe and Fittings" (EA-3)
- ☐ "PYREX Cascade Coolers" (PE-8)

Name_____

Title_____

Company_____

Street_____

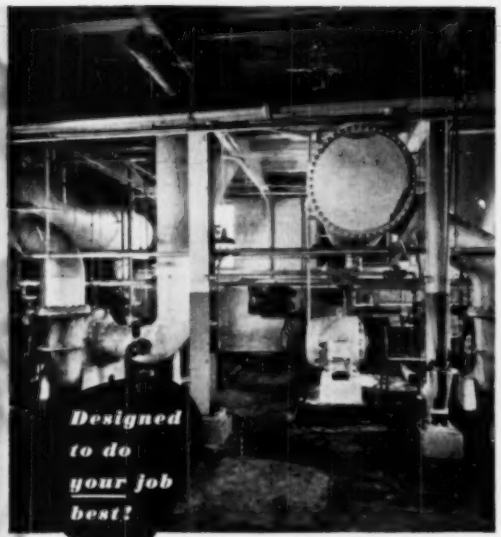
City_____

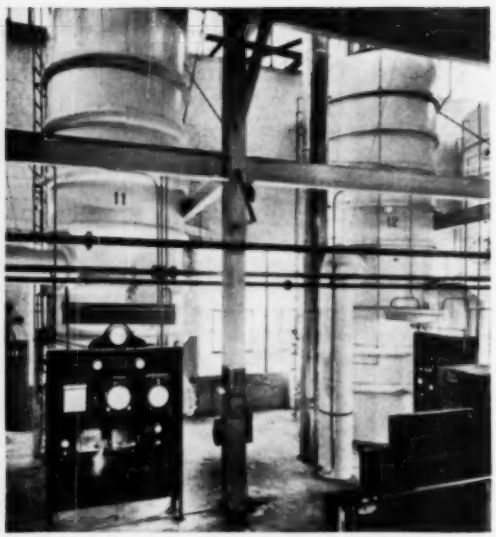
Zone_____ State_____

See General American for

CREATIVE EVAPORATOR ENGINEERING

Reduce scale deposits . . . Boost production with Conkey forced circulation horizontal tube evaporators





Liquids that tend to "scale up" need not push down your production. The Conkey forced circulation horizontal tube evaporator circulates large volumes of liquid at high velocities—through submerged and flooded tubes. In many cases, this scrubbing action is sufficient to greatly retard coating of tubes, even eliminating the scaling problem entirely.

Top production with top economies are assured by Conkey's unique design. A far smaller heating surface is required because of the high heat transfer coefficients obtained by forced circulation.

Whatever your special concentration problem may be, consult General American. Each installation is designed, engineered and built to fit your specific needs. Evaporators are built in a wide range of weldable metals. When required, special metals to resist corrosion, erosion and contamination can be furnished. Get technical bulletin on evaporators for your files.

Other General American Equipment:
Turbo-Mixers, Evaporators, Dewaterers, Dryers, Towers, Tanks, Bins, Pressure Vessels

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Sales Offices: 10 East 49th St., New York 17, N. Y.
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The De Nora Cells At MUSCLE SHOALS

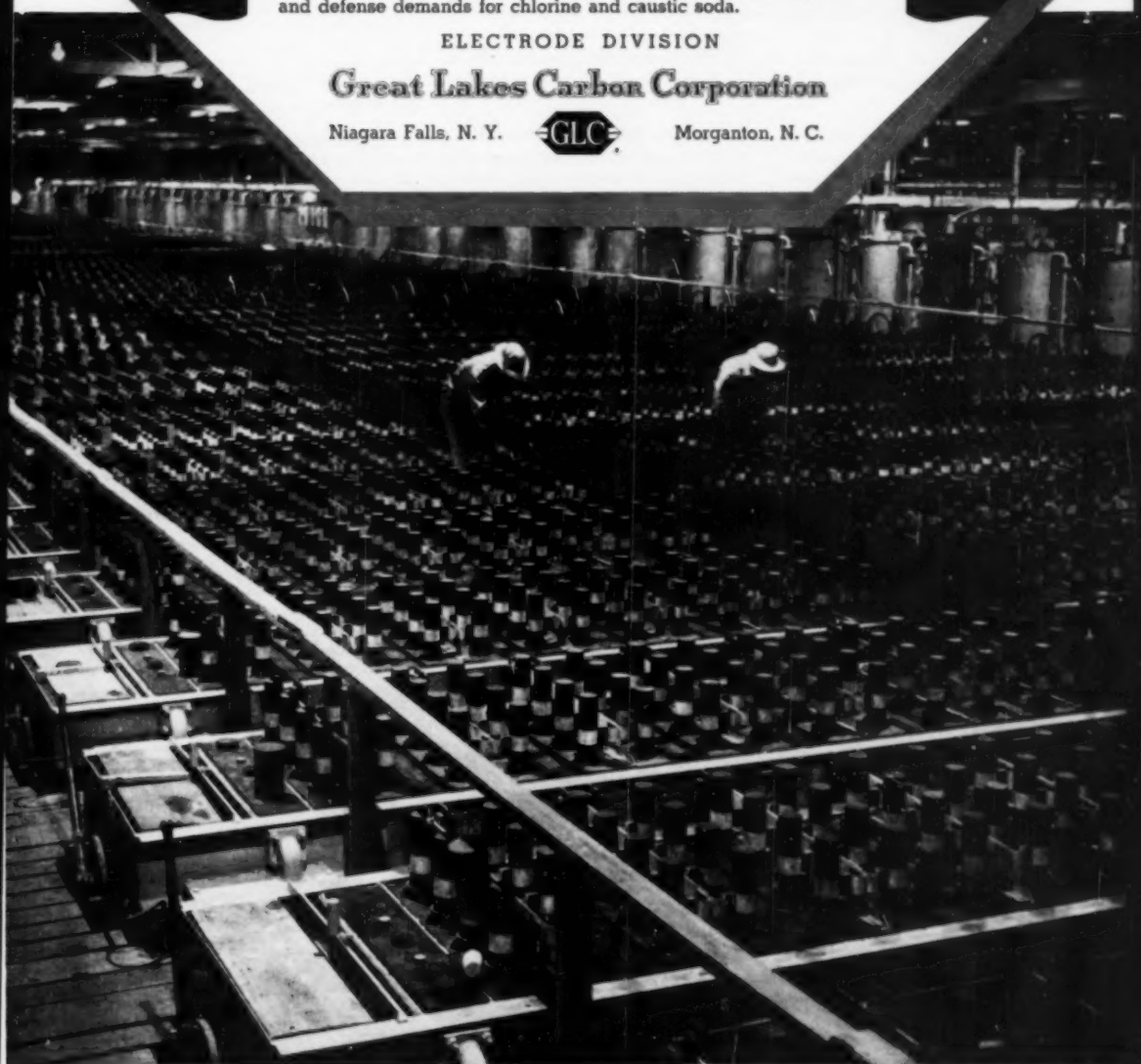
The De Nora cells at the new Government-owned, Monsanto-operated chlorine plant, Muscle Shoals, Alabama, are eloquent testimony to chemical engineering progress.

Uniformly high quality GLC GRAPHITE ANODES are doing their share to help the electrolytic industry meet the ever-increasing civilian and defense demands for chlorine and caustic soda.

ELECTRODE DIVISION

Great Lakes Carbon Corporation

Niagara Falls, N. Y. GLC Morganton, N. C.



Courtesy Monsanto Chemical Company

Graphite Anodes, Electrodes and Specialties

Sales office: Niagara Falls, N. Y. **Other offices:** New York, N. Y., Chicago, Ill., Pittsburgh, Pa.

Sales Agents: J. B. Hayes, Birmingham, Ala., George O'Hara, Long Beach, Cal., Great Northern Carbon & Chemical Co. Ltd., Montreal, Canada.

HOW MUCH DO FILTER

Have you ever thoroughly investigated both the direct and indirect cost of filter cloths in your plant? If not, the chances are you will be surprised to find that annual cloth replacement and maintenance cost alone runs from $1.00 to $4.00 per square foot of press area per year, depending on the utilization of your press, the product and the type of fabric you use.

Other costs associated with use of cloths, such as the labor for scraping, handling, washing; breaking and redressing the press; and purchasing time expended in obtaining the cloth you need when you need it will probably be even greater, even if not as easily pinned down.

Here then are three immediate reasons why you should consider switching to modern high-speed Niagara pressure leaf filters:

1. Niagara filters require no filter cloths. Accurate case histories in our files show that some plants amortize their Niagara filters in a few years on this saving alone.

2. Niagara filters require less labor. When you eliminate filter cloths, you eliminate the back-breaking and costly labor that goes with them. With Niagaras you get a quick, easy, clean operation that takes only a few minutes for one man between cycles.

3. Niagara filters work harder for you. Reduced downtime means more production time and therefore higher production at your filter station. The filter works for you more hours per day—gives you many more gallons throughput with less installed filter area.

●

By switching to Niagaras, many press users have realized over-all savings that amortize the cost of the new filters in months.

Entirely aside from savings, here are nine sound reasons for installing Niagara Filters:

1. Higher flow rates on an equal area basis. Niagaras normally give flow rates 2 to 5 times those of conventional cloth-covered filter presses. This is because the rigid metal screens do not "give" under pressure—cannot obstruct flow channels in the drainage member as does sagging fabric cloth.

2. Sparkling filtrate clarity. Positive removal of solids to practically any degree of clarity you desire. In sanitary applications, 0-0 bacteria count can usually be secured in one filtration.

3. No leakage. Fully enclosed, pressure-tight construction eliminates drippage and fumes. Ideal for handling flammable, explosive, toxic, volatile, or highly obnoxious liquors.

4. Excellent cake-washing characteristics. Nearly true displacement washing is obtainable. Wash liquid is a minimum.

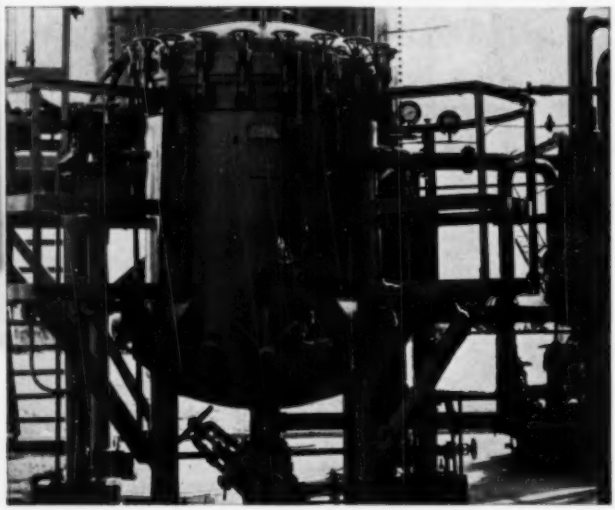
5. One-man operation and cleaning. Single or multiple units can be operated and cleaned easily by one man. The entire leaf battery is accessible for easy cleaning.

6. Corrosion resistance. The pressure leaf filter can more cheaply and readily be constructed of stainless steel, nickel, monel and other corrosion-resistant materials.

7. Jacketed construction. Niagaras can readily be supplied with steam jackets or special insulation.

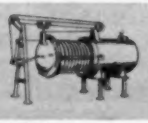
8. Wide capacity range. Sizes range from 20 to 950 square feet of filter area, with average capacity of 10 to 425 G.P.M. in one compact unit. (Even larger areas are available in the new horizontal filter shown at right on the opposite page.)

9. Lower maintenance cost. There are no moving parts during filtration. Simple construction, with fewer parts to wear out, means low-cost upkeep.



THIS NIAGARA FILTER, in large petrochemical plant, removes iron sulfide particles from solutizer solution.

Niagara Filter CORPORATION

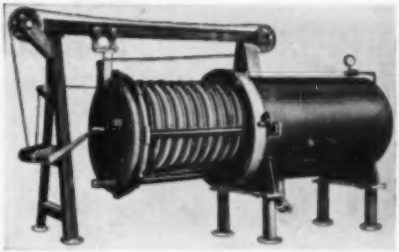


HORIZONTAL for non-aqueous liquids; high solids; cake recovery.

IN EUROPE—NIAGARA FILTERS EUROPE, 36 Leidsegracht, Amsterdam-C, Holland

CLOTHS COST YOU?

NEW NIAGARA STYLE H* FILTER
Low cleaning time . . . no cloth cost



This new Niagara filter answers the need for a filter which can quickly discharge large quantities of semi-dry cakes. A variation of the standard Niagara design, it still retains all the basic advantages of Niagara vertical pressure leaf filters.

A retractable carriage permits all leaves to be withdrawn at once for rapid cleaning. One man can easily discharge as much as 150 cu. ft. of semi-dry cake in a matter of minutes merely by rapping the leaves.

A new closure design, the Q/O* (quick-opening) cover, permits faster, easier opening and closing than ever before in a filter of this size.

The Style H filter, available in sizes up to 1500 sq. ft., is ideal for filtration where high percentages of solids must be removed or where solids must be recovered. It is also recommended for standard liquid clarification where low headroom or other special reasons make its horizontal construction preferable to a vertical filter.

*Trade Mark Patent Applied For.

HOW THE NIAGARA FILTER WORKS

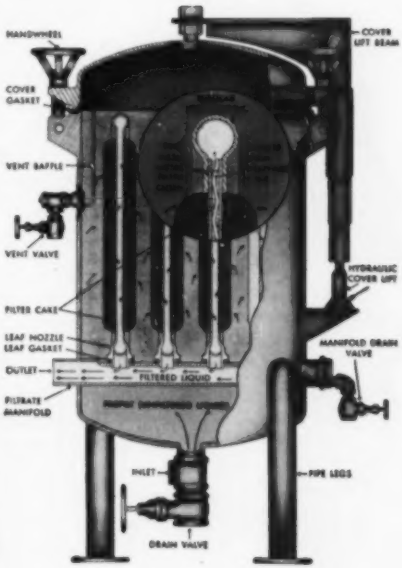
The leaves, which are the heart of the filter, consist of double-faced screen assemblies bounded by a tubular drainage frame leading to an outlet nozzle.

The unfiltered liquid usually with filteraid in suspension is pumped into the closed pressure filter tank in which the leaves are placed, and is forced through the fine-mesh screens, on which the filter cake is formed by the solids in the liquid.

Only the clear liquid reaches the inside of the leaves, flowing through the coarse center drainage wire to the tubular frames, and out through the leaf nozzles to the manifold.

When the batch has been completely filtered, or when the cake has nearly filled the space between the leaves, the filter is emptied and the filter cake is sluiced from the leaves with a hose or with automatic high-pressure sprays. Sluicing is done without removing any parts from the filter. (Cake removal for the Style H filter is somewhat different, as described above.)

As a rule, the filter is ready to go to work again in 15 minutes to one hour, depending on its size.



THESE 5 SERVICES HELP MAKE HIGH-SPEED, LOW-COST FILTRATION A REALITY IN YOUR PLANT:

1. Nationwide field service. Niagara representatives in 24 cities know filtration and can give you facts.

2. Modern filtration laboratory determines your requirements accurately by test-filtering samples of your materials.

3. Pilot filter rental plan enables you to "preview" Niagara performance in your plant, at low cost.

4. Custom engineering. A single filter or a complete system, designed for your needs and built in materials of your choice.

5. Installation and start-up are supervised by Niagara factory engineers, always on call.

PILOT FILTER duplicates operation of large production models.

Operating figures prove the economic soundness of replacing cloth-covered presses with Niagara filters. For details, write us today. Or mail the coupon for descriptive literature.

STANDARD VERTICAL — for clarification and "polishing".

"AUTO-SLUICE" for fully automatic cake sluicing.

NIAGARA FILTER CORP., 3091 Main St., Buffalo 14, N. Y.

Please send: ☐ General literature; ☐ Data on horizontal filters; ☐ Data on pilot filter rental

Name_____

Title_____

Company_____

Address_____

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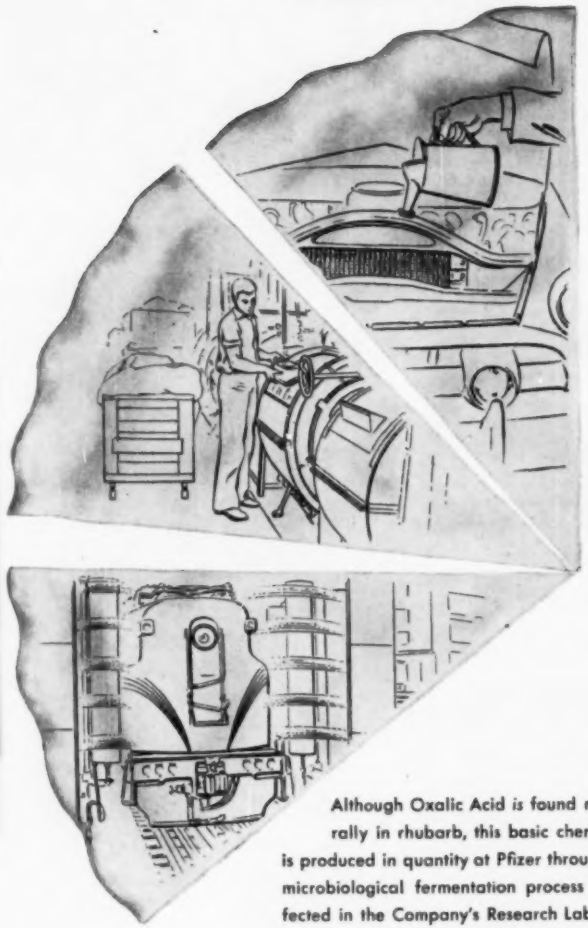
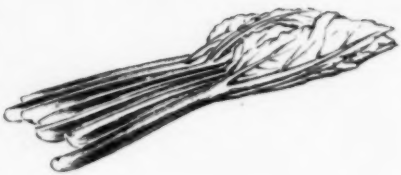
Rhubarb's Fine for Pies...





but it won't

fill your needs for

Oxalic Acid

Although Oxalic Acid *is* found naturally in rhubarb, this basic chemical is produced in quantity at Pfizer through a microbiological fermentation process perfected in the Company's Research Laboratories. The Pfizer process yields Oxalic Acid of high purity.

Because of its ability to solubilize iron oxide, Oxalic Acid is highly effective as an ingredient of metal cleaning compounds, in radiator flushes and as a rust remover in textile and leather processing. Its bleaching properties make it useful as a laundry sour and in the treatment of straw, cork and leather.

For more detailed information on the varied uses of this important organic acid, write for Technical Bulletin #34.

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AGITATORS

FOR QUICK AND THOROUGH DISPERSION OF

LIQUIDS · GASES AND SOLIDS

This new Struthers Wells booklet illustrates and describes in detail—the fundamentals of four types of liquid agitation: 1. Propeller, 2. Open Impeller, 3. Shrouded Turbine, 4. Radial Propeller. The booklet presents technical data, photos, dimensional drawings and size details on a variety of pressure vessels in which agitators are used.

Included in the brochure are Marine Propeller Agitators, Radial Propeller Agitators, Agitator Drives and an advanced Agitator Design for quick dispersion of liquids, gases and solids. Mixing equipment is shown, for solids, semi-solids, pastes and liquids. Also, drawings and data are included on custom-made pressure vessels made to standard design.

Copies of this booklet—No. 58W—are free upon request. Use your letterhead, please.

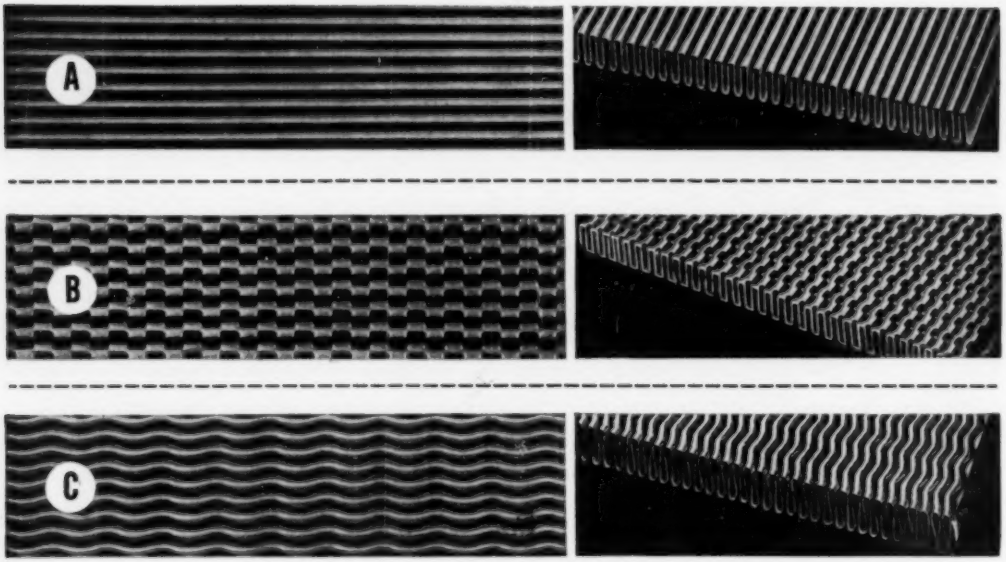
WRITE FOR YOUR COPY TODAY

Struthers Wells

Struthers Wells Corporation

PROCESS EQUIPMENT DIVISION • WARREN, PA.

Plants at Warren, Pa. and Titusville, Pa.



Three of the many types of fin section available.

TRANE Brazed Aluminum Heat Exchangers Offer Wide Choice of Heat Transfer Surfaces for Greater Design Flexibility

With Trane Brazed Aluminum Heat Exchangers, you choose from a great variety of surfaces in solving exactly your heat transfer problems. They may be straight and continuous (A). They may be serrated (B). Or they can be of herringbone design (C). With these basic designs, exactly the right surface can be selected to provide the correct ratio of heat transfer to pressure drop characteristics.

Many further variations of these general types are practical. The height and the thickness of the fin can be varied. So can the number of fins per inch. In fact, fins with entirely different patterns, heights and number of corrugations per inch can be used side-by-side to handle different fluids in the same exchanger.

Thanks to this great flexibility you can provide just the heat transfer, just the pressure drop volume, velocity number and direction of passes you want with Trane Brazed Aluminum Heat Exchangers.

Design flexibility is but one of the many advantages of Trane Brazed Aluminum Heat Exchangers. Compared to conventional exchangers, they produce more heat transfer efficiency in ¼ the space with ⅓ the weight at approximately ½ the cost.

These all-aluminum heat exchangers are rugged, too. They take test pressures up to 1,000 pounds per square inch and temperatures from −300° to 500° F.

Whether the job calls for high or low temperatures or pressures, one stream or many, Trane Brazed Aluminum Heat Exchangers can be the answer. Contact your Trane sales office or write direct.

Here are a few of the many varieties of Trane Brazed Aluminum Heat Exchangers which are now in actual service: 1) A cross flow unit for liquid-to-gas exchange used for condensing purposes. 2) A cross flow gas-to-gas unit which is used for intercooling for aircraft engines. 3) A counter flow liquid-to-liquid exchanger for high pressure application.

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MANUFACTURING ENGINEERS OF HEATING, VENTILATING AND AIR CONDITIONING EQUIPMENT

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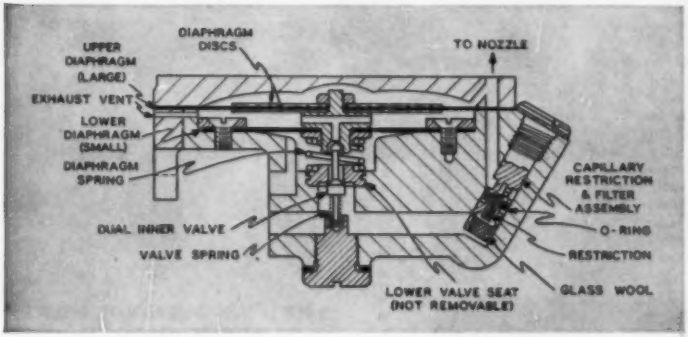
A Superior Controller

must have a Superior Relay

you get it in the

P-4 PNEUMATROL

Pneumatic Controller



HOW IT WORKS: When flapper is moved against nozzle by measuring system, pressure increases on top of large diaphragm. Floating exhaust seat moves downward pushing lower or inlet valve open increasing pressure in output circuit and under small diaphragm until balance of forces closes the valve. Conversely when nozzle is vented, the diaphragm system moves upward to open exhaust valve, reducing pressure in output circuit until equilibrium is again established.

The F&P FLOWRATOR meter was the first flow rate meter generally available to exhibit instantaneous response to flow rate change, leading to control problems that have been presented by current mechanical differential type flow transmitters.

Rapid response of the control valve is essential for stable control in a system which changes rapidly. Since the control valve action depends upon the capacity of the relay supplying it with air, the requirement for a high capacity stable relay required solution. Consequently, the P-4 relay has been designed to be extremely fast without impairing its basic sensitivity due to hydrostatic unbalance. The P-4 relay utilizes tandem slack diaphragms which provide the multiple requirements of high capacity, low air consumption "on control", and freedom from all dead zone. Write now for Catalog C-50.

9 POSITIVE BENEFITS

Versatility—one relay fits transmitter, and all case and point-of-measurement controllers.

Integral unit—permits fool-proof construction without tubing connections.

High capacity — essential for best in flow control.
Rated capacity—2 cfm @ 1 psi drop.

Capacity fully usable—transfer switch ports and connectors match relay high capacity.

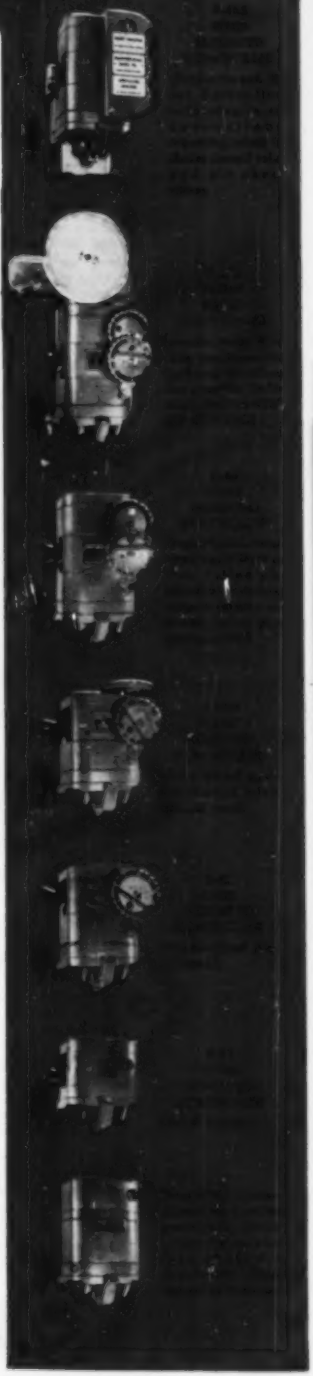
High force — friction ratio — large diaphragm area produces maximum sensitivity.

Amplification—4:1 pressure multiplication of tandem diaphragms permits low nozzle pressure, low reaction pilot system.

Protected Pilot—integral filter assembly features stainless steel restriction and nozzle.

Non-bleed—no dead zone assured by tandem diaphragm and floating exhaust seat construction.

Materials — aluminum die cast body with brass insert, neoprene diaphragms. Trim, springs and screws of stainless steel.



FISCHER & PORTER CO.

210 County Line Road, Hatboro, Penna.

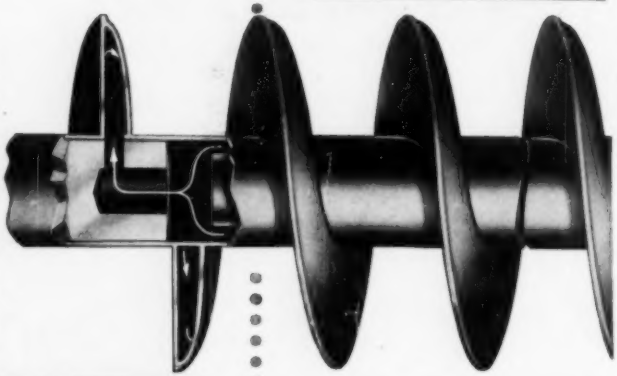
A revolutionary new principle in Coolers . . .

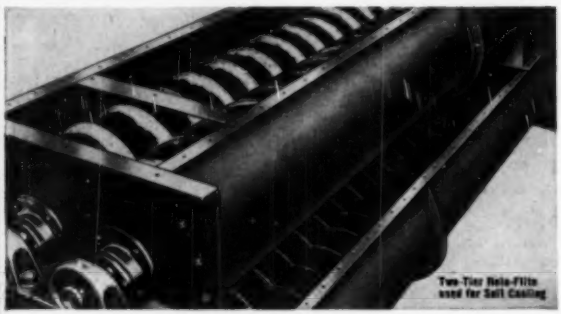
THE holo-flite* PROCESSOR

(HOLLOW-FLITE)

- Handles Pastes, Sludges or Solids!
- Up to 80% Saving in Space!
- Permits Continuous, High Efficiency Operation!

Backed by the same well-known organization that pioneered COTTRELL Precipitators, MULTICLONE Collectors and other leading products, the HOLO-FLITE Processor represents a far-reaching advancement in the science of heat-exchanger design. Widely adaptable to various types of cooling and similar applications in industrial processing operations, the HOLO-FLITE handles powdered or granular solids, moist pastes or slurries with equal facility. Moreover, it requires as little as 1/5th the space of other heat exchangers . . . causes no dust, therefore requires no costly or complicated auxiliary recovery equipment . . . and maintains its uniformly high efficiency under modern continuous-flow operations (no stop-and-go "batching" operations are necessary).





Two-Tier Holo-Flite used for Salt Cooling

Unique Simplicity

Basically, the HOLO-FLITE consists of two or more hollow intermeshing conveyor screws that slowly rotate in a trough or tube. The cooling agent circulates through the hollow flights and shafts of the conveyor screws while the product itself "flows" in the trough where it is constantly rotated into, around, over and under the moving heat-exchange surfaces. The continuous mixing, turning, folding action causes a constant change of contact with the heat-exchange surfaces and results in a high rate of heat transfer. Yet the action is so gentle that there is no dusting and little, if any, abrasion of crystalline particles.

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HOLO-FLITE Processors can be readily adapted to virtually any capacity requirement and are in daily operation on such varied products as sand, cement, cottonseed cake, soybean meal, borax, salt, sugar, baby foods, and many other products. Cooled products can be packaged directly from the HOLO-FLITE discharge, saving time, space and additional handling.

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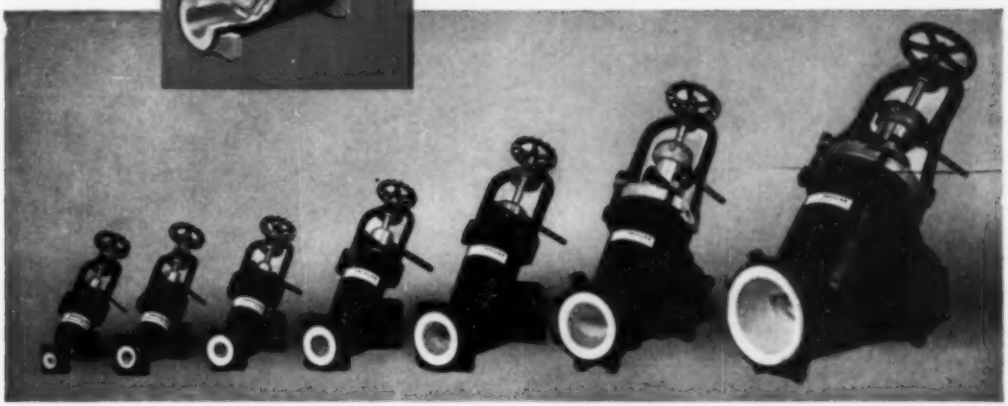

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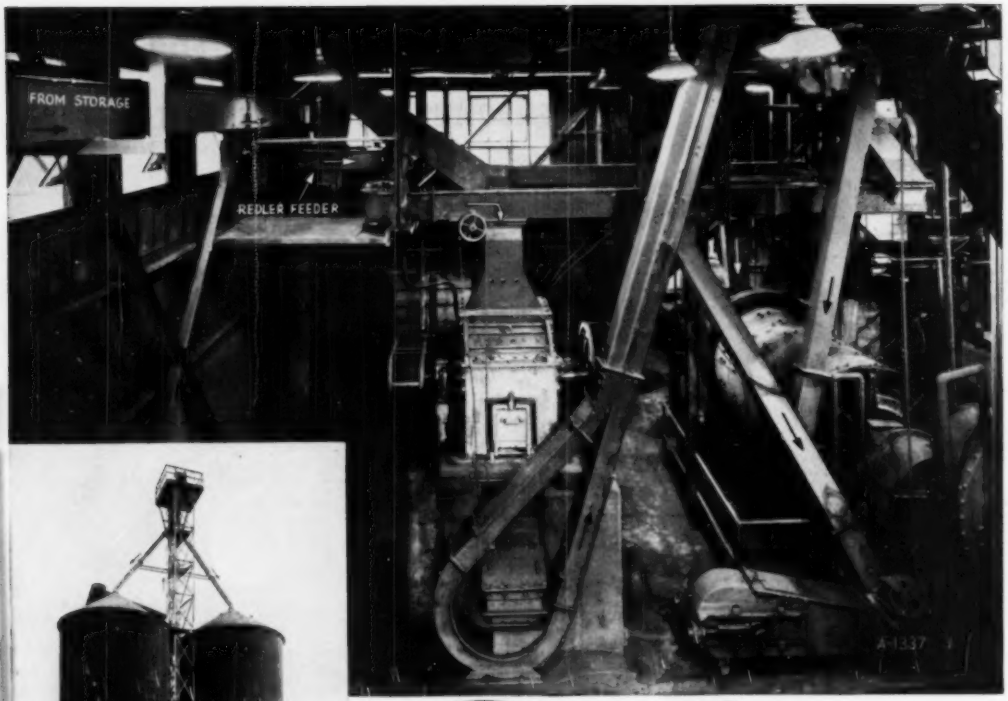

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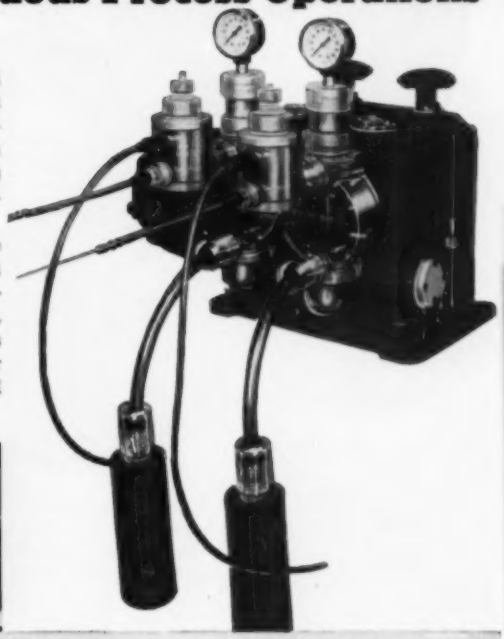


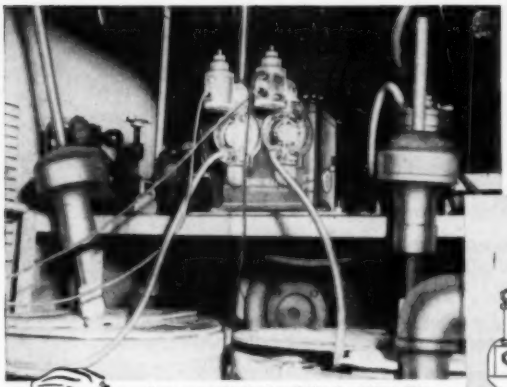
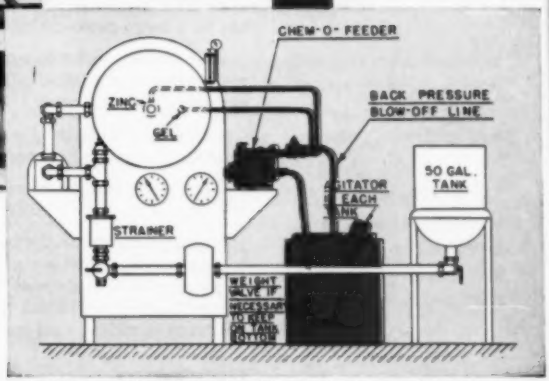


Photo courtesy The Faultless Rubber Co., Ashland, Ohio.



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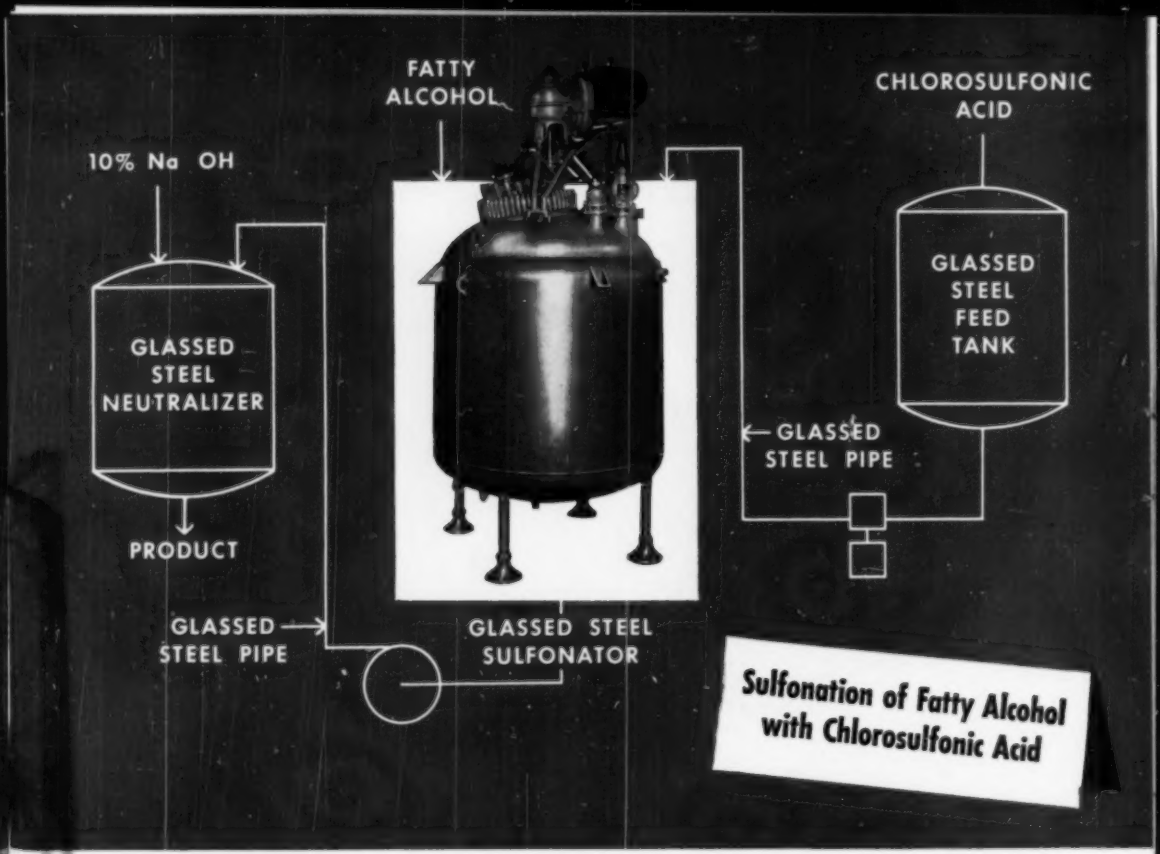

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Opinion and comment

COURAGE TO HELP COURAGE

WHEN one stops to think about the problems facing the young men and women of our age, it is apparent that the quality needed in the largest measure is courage. This is not to say that other generations had no need of this wonderful element of the human spirit—they did. But few eras in the history of our country have ever produced so many confusing and paralyzing events for the young, for the college and pre-college crowd, as these past few years. Heretofore when our nation was faced with an enemy or a problem, the issue was squarely met and overcome. The young men involved in our wars stood up to the terror and uncertainty, overcame it, and were able to plan, and follow their own inclinations and dictates. There were bleak years, to be sure, lives were blighted, but after the torment, the future lay for the majority comparatively serene. At least one could plan. Previously the world's travail was similar to a wild hurricane—devastating while it lasted, but the sun was sure to come out afterward. Then a man could plan and work in a peaceful atmosphere.

Well, now, by comparison, the problems are torturous. There is a never-ending pressure on our security, deliberate undermining of our faith in the future, moves and strategy all designed to confound our principles and weaken our will. Democracy, by its very nature, cannot countermove similarly; its only weapon is truth and preparedness—and the latter is the origin of much of the confusion for our young. Above all their moves and lives, over all their planning lies the uncertainty of selective service, Korea, the cold war, and all the attendant cries and alarms of two systems of thought struggling for dominance. And through it, we expect the healthy, uncowed planning of youth for careers and professions. Yes, our youth is living up to the demands of our life in many respects, but on the other hand, we are aware of dissenting voices, for the temptations are great. Why plan, why strive for an education with the threat of draft always there? Delay plans, delay education until after your period of service; if you have to go to college now, take ROTC, go the arguments. Always, over all their plans, is a sense of temporary living, waiting for other forces beside their own, to shape their lives; a sense of catastrophe. They need courage, and the wonder of it all is that the United States today can look at the colleges and universities and be reassured that the supply of professional men, of educated men and women will continue unabated.

And in the encouragement of the young to continue their education our present professional organizations and their members can render a service. I feel certain that the past records of achievement, the professional pride and advancement of all our professions have helped in the preservation of youthful hopes. The young also wish to participate someday in the future. Despite the uprootedness of our world, somehow they have sensed the need for special skills and for trained minds.

We can continue to keep such hopes alive. As chemical engineers we have a major responsibility for one of the massive wealth- and job-producing industries of this civilization. The hope for the future economic well-being is in an expanding technology, newer things, less expensive things, more and better foods, clothing, and housing, the utilization of all the world's resources for all the world's needs. Through the full application of our knowledge and our energies our industry will spurt ahead—it seems unlikely that it will not. In that respect we are extremely professional, we are meeting the challenge of our education. But in other respects we need more effort, more courage. Military service is an undigested lump in our life and philosophy—how many of our technical men are giving this problem attention? Do we try to work out sensible procedures with the selective service organization, or do we accept the drafting of our competent young men as inevitable? How often do our technical men make known to local colleges their willingness to talk to students about the industry, and the future—and how often do the professors seek out such men? Our local sections, do they have student nights? Do they welcome and dine the students at least once a year, listen to the ideas, the problems, and the solutions that appeal to the current crop? All these are little acts in themselves, but they are important acts in keeping the hope and courage alive of a generation that truly has a date with destiny. Just as the longest journey begins with a single step, so the rebuilding of our world must begin with little acts—little acts of courage.

F. J. VAN ANTWERPEN

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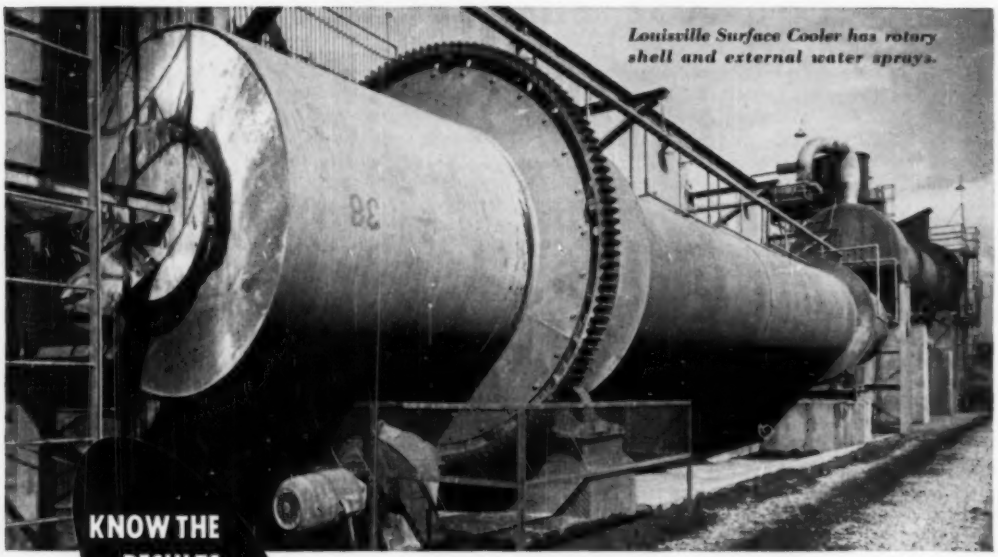

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High-Vacuum Vapor Pumps

A New Synoptic Presentation of Their Characteristics

In selecting a vapor pump (diffusion pump) for a given application, certain characteristics are of primary interest—lowest obtainable pressure, volumetric speed as a function of inlet pressure or of throughput, throughput limitations at high inlet pressures, and maximum allowable forepressures. Most of these quantities cannot adequately be expressed by a single number because of various interrelations. It is desirable that these and other characteristics be made evident in a fashion which is at once succinct and detailed, easy to interpret correctly, and difficult to misinterpret.

The graphical presentation discussed here has been evolved and tested and found highly useful. A single sheet of log-log paper displays inlet pressure, typical operating forepressure (for a specific forepump), and maximum tolerable forepressure, all as functions of throughput. Speed can be read directly either as a function of inlet pressure or of throughput. Effects of various forepump capacities or of varying heater input can be shown without undue complication. The curves lend themselves readily to other uses besides the important one of rendering proper pump selection easy.

R. B. Lawrance

Richard B. Lawrance, director of the applied physics department, National Research Corp., Cambridge, Mass., received his training at Massachusetts Institute of Technology. Upon receiving an S.B. in electrical communications in 1940, he joined the newly formed M.I.T. Radiation Laboratory, where he participated in the development of the widely used Loran radio navigation system. After the war he returned to M.I.T. as a graduate student in physics, receiving the Ph.D. degree in 1949. Since joining National Research Corp. early in 1950, he has been extensively concerned with apparatus, instrumentation, and processes involving high vacuum.

THIS paper deals with methods of measuring and presenting the most useful performance characteristics of a large class of high-vacuum vapor pumps. As a matter of terminology, these pumps have been known as diffusion pumps, condensation pumps, and vapor pumps. In order to avoid some formerly controversial connotations, the latter term will be used here. By vapor pump, therefore, those devices will be denoted wherein a working fluid is boiled; conducted as a vapor to a pumping chamber; projected as a high-speed oriented stream or curtain of vapor into the gas being pumped; condensed on a wall or other bounding surface; and returned as liquid to the boiler. The discussion is thus directed specifically toward the several types known as high-vacuum pumps, booster pumps, and ejector pumps. These pumps do not exhaust into atmospheric pressure, and consequently require an auxiliary forepump or backing pump, almost always of the rotary oil-sealed variety. Steam ejectors will not be explicitly considered, although they can readily be treated according to the present method.

It seems worth while here to include a brief outline of the mode of operation of a typical high-vacuum vapor pump, in order that the subsequent discussion may be made more meaningful to those who, although perhaps not presently familiar with such groups, may yet be directly concerned with their use. Figure 1 shows a cross section of such a pump of the so-called high-vacuum purifying or fractionating variety (the term "purifying" refers to the action taking place in the boiler, where the pumping fluid—an organic oil—is purified by a crude fractionation). The pump shown is contained in a cylindrical stainless steel casing and all parts are figures of revolution, with the exception of the foreline which is connected as a side tube.

The action of the pump depends on myriad individual collisions of oil-vapor molecules with molecules of the air (or other gas) being pumped. The oil-vapor molecules are emitted from the jets—here three in number and annular in shape—with velocities approximately equal to that of sound, and the jets are shaped to make the emitted oil vapor thrust strongly downward and outward. Air molecules traveling in a comparatively random fashion enter the region occupied by the jet and suffer collisions with the much heavier oil molecules; this driving rain of oil molecules propels the air generally downward, thus compressing it.

Three successive stages of such compression are shown in the pump of Figure 1: by the time the air has traversed the lower jet and entered the foreline, it is sufficiently compressed to

be handled satisfactorily by the rotary mechanical forepump. Typical compressions produced by the vapor pump range from a factor of one million (for very low inlet pressure) to factors of less than ten.

It should be emphasized that many other designs of vapor pumps are in use and that booster or ejector pumps in particular may look different from the pump of Figure 1.

The basic information needed by the potential user of a pump may be classified as follows:

First, there are the dimensions and requirements for heating and cooling.

Second, there are what may be termed the gross details of performance and of auxiliary equipment requirements. For example, what is the pressure range over which the pump operates satisfactorily? What is the speed as a function of inlet pressure over the operating pressure range? Alternatively, what is the gas throughput as a function of inlet pressure over the operating pressure range? What is the lowest pressure attained for essentially zero throughput (the "blankoff" pressure)? How low a forepressure (or "backing" pressure) must be maintained by the forepump? What penalty is incurred if this tolerable forepressure is exceeded?

Third, there are many more detailed questions as follows: What performance can be expected with a particular forepump? How will performance be affected by the use of a larger or smaller forepump? What will be the effect of varying heater input? How does the pump perform when pumping other gases or vapors, such as hydrogen, argon, or water vapor?

Some time ago the author and his associates came to the conclusion that there was room for improvement in the methods of specifying and presenting the answers to these questions, and evolved a graphical presentation which was found helpful and which they believe merits consideration for more widespread use. A single sheet of graph paper is used to display the answers to the most important of the questions outlined above, namely, the performance of the pump throughout its useful operating range of pressures and a rather complete graphical statement of the forepressure characteristics. A little effort is required in learning to read the graph but once its presentation is understood, the properties of any pump, so specified, can be completely comprehended at a glance, without further calculation. Thus, as with the multiplication table, the initial effort is well repaid.

Consider briefly the methods by which a vapor pump is tested:

Figure 2 gives a sketch of the setup used in testing a typical medium-sized pump. With the vapor pump and forepump running, the first step is to open the inleak throttle V_i, meanwhile observing the inlet pressure P_i, until some suitable value of gas throughput Q is obtained. This value of Q is measured by manipulating the three-way stopcock so that the pump draws its gas from the gas flow gage and displaces the manometric fluid. A stopwatch is used to measure the time required to exhaust a known amount of gas, by timing the successive transits of two fiducial marks, and the throughput Q is immediately obtained by division. The inlet pressure P_i is read and recorded, using the hot filament ionization gage for pressures below about five microns, and a radium-source Alphatron ® ionization gage for pressures above about one-half micron. Thus a corresponding pair of values Q, P_i is established.

The operating value of forepressure P_f is also recorded, and the next step is measurement of the maximum tolerable forepressure. This measurement, for each value of throughput Q, is one of the salient features of the present method. Additional air is introduced into the foreline via the throttle V_i, until some standard medium-value forepressure is obtained. The valve V_i is then carefully throttled down to increase the forepressure slowly, the inlet pressure gage being watched meanwhile. The variation of inlet pressure P_i with forepressure P_f is indicated in Figure 3. It is an experimental fact that with a well-designed pump the inlet pressure will be independent of forepressure, within the accuracy of measurement, for all values of forepressure below some particular value. For forepressures higher than this value, backleakage becomes significant, and the inlet pressure rises (the throughput Q is constant throughout the measurement). It has been found useful to define and measure the quantities P_{fl} and P_{fb}, representing respectively the tolerable and breaking forepressures for the particular value of Q. These quantities correspond respectively to ten per cent and tenfold increase in P_i.

Measurements just indicated, for a particular value of Q, are repeated over the complete range of throughput values, from zero up to a value which completely overloads the pump. The salient characteristics of the pump may then be presented on a single sheet of log-log paper, as shown in Figure 4, with four curves of inlet pressure P_i, typical operating forepressure P_f, tolerable forepressure P_{fl}, and breaking forepressure P_{fb} being plotted against throughput Q. As a matter of esthetics the independent variable Q has been plotted as ordinate and the dependent pressure variables as abscissas.

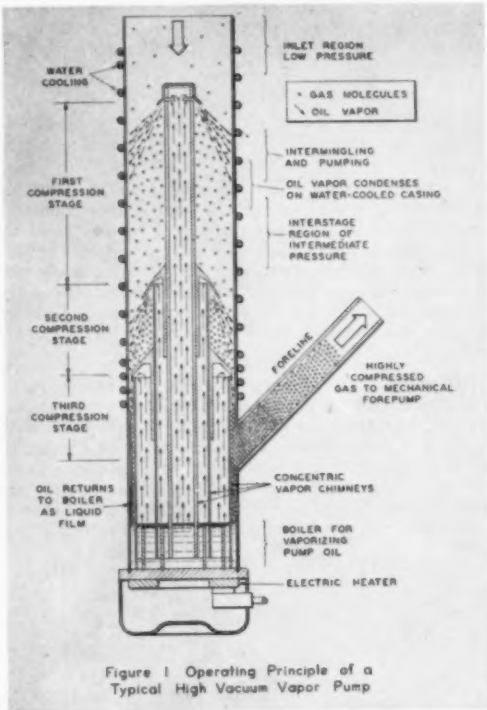

Figure 1 Operating Principle of a Typical High Vacuum Vapor Pump

Curve 1 in Figure 4, showing the relationship between throughput and inlet pressure, includes all features of the conventional presentation of volumetric speed S vs. inlet pressure. Speed, it will be remembered, is calculated as the ratio of throughput (micron liters per second) to the inlet pressure (microns), giving the speed S in liters per second. (As mentioned earlier, modification of this definition is occasionally made in the lowest blankoff pressure range). Lines of constant speed thus appear as forty-five degree diagonals, logarithmically spaced in extremely convenient fashion. Thus the single curve of inlet pressure vs. throughput can be read as P_i vs Q, Q vs P_i, S vs P_i, or S vs Q.

Measurement shows that at a high pressure the throughput Q rises but

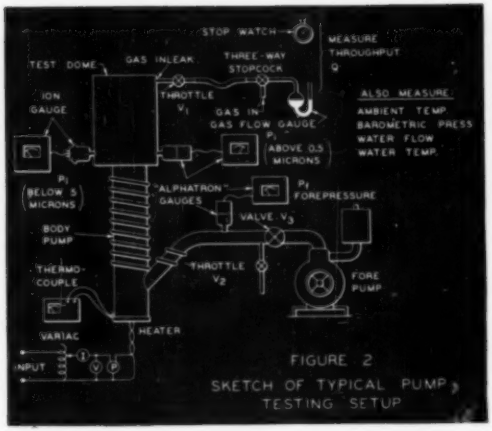

FIGURE 2
SKETCH OF TYPICAL PUMP TESTING SETUP

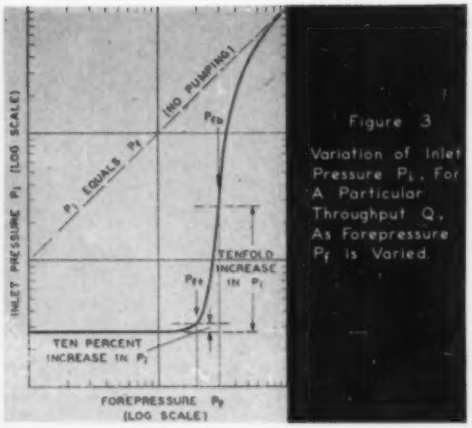

Figure 3
Variation of Inlet Pressure P_i, For A Particular Throughput Q, As Forepressure P_f is Varied.

slowly with increasing inlet pressure, which implies that the speed decreases almost in inverse proportion to the inlet pressure. One of the most serious criticisms of the usual speed-vs-pressure characteristic curves is the fact that this portion of the curve is highly susceptible to errors in drafting. The physical fact that the throughput does increase monotonically with increasing inlet pressure, even though slowly, is always concealed and often even unwittingly falsified. By contrast, our method of presentation is completely free of this objection.

All the familiar features of pump performance are readily recognized in curve 1. The blankoff pressure (or more properly the blankoff indicated pressure) is the value approached by P_i as the throughput is reduced toward zero and the inlet pressure curve plunges vertically. The mid-region of constant speed is readily recognizable as a flat portion with forty-five degree slope, and the value of speed is read from the forty-five degree coordinates. The fact that above a certain throughput the pump operates with increasing reluctance is made plainly evident in that a small increase in throughput, in this high-throughput region, produces a much more than proportional increase in inlet pressure.

As concerns the second curve, giving typical operating forepressures obtained with a generally suitable forepump, this curve can usefully be compared with the manufacturer's data. Incidentally, the compression accomplished by the vapor pump can easily be obtained, for any given throughput, as the horizontal distance between the inlet pressure curve and the operating forepressure curve.

The third curve, as should be plain from the preceding discussion, forms a right-hand boundary: for a given throughput Q any forepressure less than the value P_{ft} given on curve 3 is satisfactory. This implies that if desired, a smaller mechanical forepump can be substituted for the particular forepump of curve 2; the smaller forepump will cause a deterioration in high-throughput performance but none whatever in performance at medium and low throughputs. Conversely, a larger forepump can improve the performance at high throughputs, within limits. The principal thing to remember about curve 3, therefore, is that it forms a boundary in the sense that all lower forepressures are perfectly satisfactory, while all higher forepressures are increasingly unfavorable.

Curve 4 represents a fixed high degree of back-leakage. The lateral separation between curve 3 and curve 4 thus gives an index of the rapidity with which pump performance deteriorates as the forepressure is increased over the values of curve 3. It is not true for all pumps that curve 3 and curve 4 remain closely spaced for the lowest values of throughput: the satisfactory operation of a high-vacuum pump at a blankoff pressure of

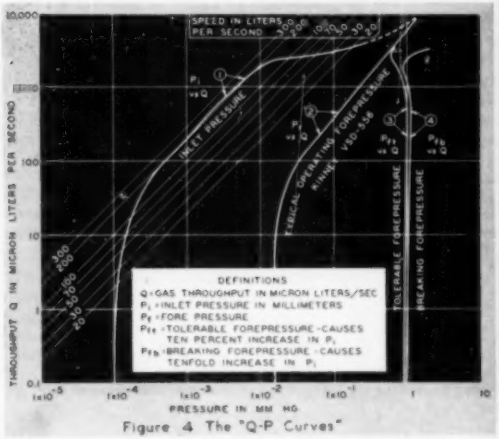
SPEED IN LITERS PER SECOND
INLET PRESSURE
TYPICAL OPERATING FOREPRESSURE
TOLERABLE FOREPRESSURE
BREAKING FOREPRESSURE
DEFINITIONS
Q = GAS THROUGHPUT IN MICRON LITERS/SEC
Pi = INLET PRESSURE IN MILLIMETERS
Pf = FORE PRESSURE
Pft = TOLERABLE FOREPRESSURE - CAUSES TEN PERCENT INCREASE IN Pi
Pfb = BREAKING FOREPRESSURE - CAUSES TENFOLD INCREASE IN Pi
THROUGHPUT Q IN MICRON LITERS PER SECOND
PRESSURE IN MM HG

Figure 4 The "Q-P Curves"

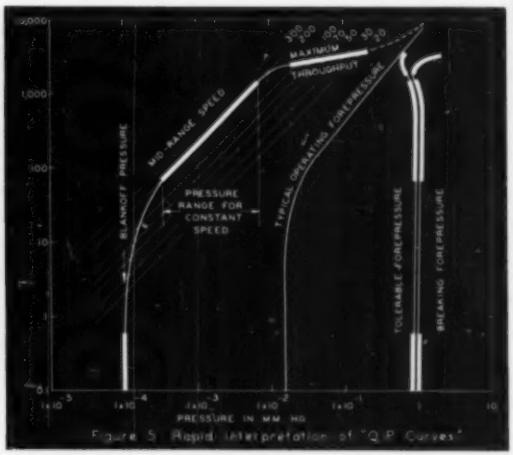

Figure 5 Rapid interpretation of "Q-P Curves"

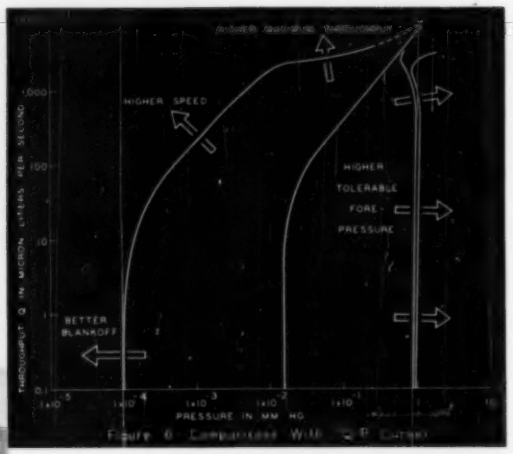

Figure 6 Comparisons With Q-P Curves

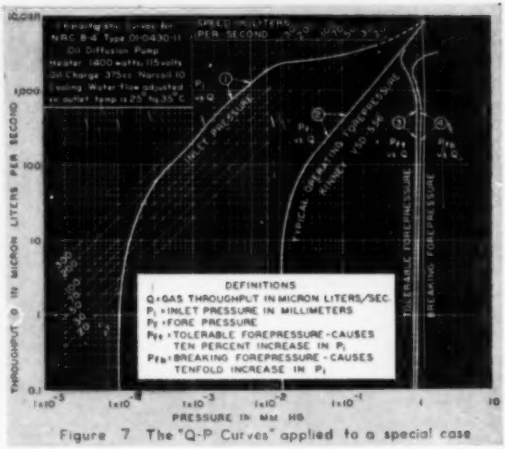
SPEED IN LITERS PER SECOND
DEFINITIONS
Q = GAS THROUGHPUT IN MICRON LITERS/SEC.
P_i = INLET PRESSURE IN MILLIMETERS
P_f = FORE PRESSURE
P_{ft} = TOLERABLE FOREPRESSURE - CAUSES TEN PERCENT INCREASE IN P_i
P_{fb} = BREAKING FOREPRESSURE - CAUSES TENFOLD INCREASE IN P_i
THROUGHPUT Q IN MICRON LITERS PER SECOND
PRESSURE IN MM HG

Figure 7 The "Q-P Curves" applied to a special case

less than 10^{-6} mm. may require a fairly low forepressure, which would be indicated by a pronounced fillet-like curvature of curve 3 (and possibly also curve 4) toward lower pressures.

After a certain amount of work in learning how to use these Q-P curves, one is in a position to benefit from their intrinsic usefulness. Figure 5 shows how various important characteristic values can be obtained by inspection. The blankoff pressure, mid-range speed, pressure range over which this speed is obtained, maximum throughput, and complete forepressure characteristics can be read at a glance.

Figure 6 shows how improvement of various performance characteristics shifts the curves; in general the more remote from the central region of the graph the better.

The fact that quantitative information is easily and accurately conveyed is evident from the complete curve of Figure 7 which differs from Figure 4 only in the inclusion of nameplate data and a more complete drafting of the logarithmic coordinates. It is proposed to have special graph paper manufactured so that experimental performance data may be put directly into the synoptic presentation under discussion.

Conclusion

In conclusion, it may be well to point out that inevitably some potentially useful information is not included in the presentation discussed. Operation with heater input other than that specified will shift the position of curves 3 and 4 and will make changes in the high-pressure end of curve 1; slight changes in the low-pressure end may also result. Operation with other gases, such as hydrogen, helium, argon, or water vapor will produce drastic changes, generally predictable by the designer. As mentioned earlier, the use of a larger forepump will, within limits, increase the maximum throughput. All these out of the ordinary performance characteristics are easily presented by simply drawing extra complete sets of Q-P curves in a format identical with that which has been discussed. Alternatively, when the curves have become familiar, it will be a simple matter to include on the same graph the curves corresponding to two or three different forepumps.

Notation—Definition

Q = throughput of gas being pumped (micron liters/sec.)

Obviously other common units can be used, provided that units of pressure and volumetric speed are made consistent. Typical alternative units for Q are micron cubic feet per minute, micron cubic meters per hour, pounds of air (or other gas) per hour, etc.

P_i = inlet pressure of vapor pump (microns or mm. Hg)

R_f = forepressure of vapor pump (microns or mm. Hg)

P_{io} = blankoff value of indicated inlet pressure

Emphasis here is on the word "indicated" since if any of a variety of ionization gages is used—hot filament, Philips cold-cathode, or Alphatron ionization gage—the reading will depend on the chemical composition of the gas. Blankoff values nearly always involve gage readings whose predominant part is due to the vapors of the pumping fluid. Since the density of these vapors can be reduced by cooling the gage element or its connecting tubulation, it is necessary to specify standard conditions for measurement. Common practice is to use a hot-filament ionization gage at some specified ambient temperature, with no cooling or vapor-trapping in the connecting tubulation. It is seldom necessary or worth while to translate the blankoff pressure readings into true pressures, and usual practice is to specify the type of gage and its blankoff reading, which is thus implicitly in terms of equivalent pressure of air.

P_{ft} = tolerable forepressure—causes 10 per cent increase in P_i for the particular throughput Q.

This term seems suitable since it is accurately descriptive and has not previously been widely used with definitions other than that given.

P_{fb} = breaking forepressure—causes tenfold increase in P_i for the particular throughput Q.

In contradistinction, the term, breaking forepressure, has been used widely and with a great variety of definitions. In some applications a pump is far from useless even when its inlet pressure has risen by a factor of a thousand; for other purposes a factor of two or three is disastrous: when then, can a pump be termed "broken"? It might be supposed that some inlet pressure such as a micron could be agreed on as representing the "broken" forepressure condition. A welter of different values would, however, be required for the several different classes of pumps and the various uses to which they are put. There seems little hope of agreeing on any useful single value; accordingly it is proposed to standardize tentatively on the factor-of-ten definition used here.

S = volumetric speed of vapor pump (liters per second)

$$S \triangleq \frac{Q}{P_i} \text{ or as occasionally defined}$$

$$S \triangleq \frac{Q}{P_i - P_{io}}$$

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Discussion

B. B. Dayton (Distillation Products Industries, Rochester, N. Y.): Commenting on your definition of breakdown forepressure: you define it as the breakdown forepressure at which the high-vacuum pressure increases ten times. For pumps which have a very low ultimate vacuum, for example, 10^{-7} mm., an increase of 10^{-7} to 10^{-6} doesn't mean that the pump is all through, although it is likely the pressure will rise quickly beyond that if your forepressure increases much. Wouldn't it be better to define breakdown forepressure in terms of some fixed increment of pressure, such as the forepressure at which the high vacuum is increased above either .1μ or $\frac{1}{2}\mu$?

R. B. Lawrance: This question is frequently asked and no answer is completely satisfactory. How should the upper limit forepressure be defined and by what name should it be called? It is necessary to establish some arbitrary convention as to the definition and means of measurement; we have used a factor of ten increase in inlet pressure and find this convenient for many purposes. Other definitions are possible and there may be others which will turn out to be preferable: this will evolve naturally when many users have had a chance to contribute their comments. With regard to the name "breaking forepressure" what is required is to find a name which conveys the idea forcefully and whose use will be confined to the agreed-upon measurement. We have felt that it was better to take a picturesque but loosely defined term in common use and make its definition more rigid, rather than trying to coin a new and equally expressive term.

B. B. Dayton: Yes, my comment was mainly in regard to your statement that the pump is all through when the pressure has increased ten times. In some cases where the pressure has increased from 10^{-7} to 10^{-6} the pump might still be holding and the increase is due mainly to back diffusion and not to complete breakdown of the jet. It's just a matter of terms. I think your definition of tolerable forepressure is a good one. The 10 per cent is perfectly acceptable. Your synoptic method of the presentation of the data is excellent. It will save space in catalogs and once we get the public educated to interpret these curves, I think this method will be a good procedure to adopt.

R. B. Lawrance: We have used this synoptic presentation in our laboratories for some time, and the present form represents a considerable modification of our original format. For instance, we used to measure inlet pressure rises of 2, 10, and 20 per cent as well as a factor of ten increase. The nature of the breakdown curves which we have measured has led us to feel that the 2% and 20% curves generally add little to the information contained in the 10% curve of "tolerable" forepressure. As indicated previously, we feel that widespread experience with the factor-of-ten value which we have called "breaking" forepressure may show modification to be desirable, and comments will be welcome.

W. L. Morgan (Libbey-Owens-Ford Glass Co., Pittsburgh 35, Pa.): Would you care to comment on the utility of the standard leaks that are available for such testing as pumping speeds?

R. B. Lawrance: The testing of pumps of greatly different sizes, over a wide range of pressures, requires known throughput values ranging over many factors of ten. For example, a pump of 1-in. inlet diam. operated at a pressure of 10^{-6} mm. might require a throughput of about 0.01μ l./sec., while a large booster pump at a pressure of 200μ could typically require 60,000μ l./sec. This throughput range can be covered conveniently either by a series of standard leaks with monitored driving pressures, or by a series of displacement manometers, as shown in Figure 2 of the text. Both methods have been used at our company, but I personally have used only the displacement manometer. As we use this instrument it is subject to a simple correction not given in the literature, but with this correction the throughput measurement is direct and not open to question. As concerns the standard leak technique perhaps all I should say is that for the low throughputs the leaks are somewhat subject to clogging and it is useful to have two (or preferably three) leaks so intercomparisons can be made.

W. L. Morgan: If you change the amperage or heating rate on your commercial pump you change the low value that you can attain. Can you use that as an indication of the back diffusion, that is, the lower the amperage generally the lower the ultimate vacuum, whereas the higher (within limits) the amperage the higher the pumping rate but the poorer the ultimate vacuum. Can you bring that out?

R. B. Lawrance: This is an interesting point. Consider a blanked-off pump, i.e., one with zero throughput. What will be its inlet pressure—the "ultimate vacuum"—as a function of heater power? Obviously for zero heater input there is no pumping and the inlet pressure is essentially that produced by the forepump. For successively higher heater inputs more and more pumping occurs and the blank-off pressure drops. For some particular heater input or range of heater inputs a minimum blank-off pressure is obtained and for still higher inputs the blank-off pressure rises, as Mr. Morgan describes. For a well-designed pump, however, there should be a considerable range of heater input values over which the blank-off pressure is a rather flat minimum. Hence it is only with poorly designed pumps that the effect mentioned by Mr. Morgan is sufficiently pronounced to be useful.

B. C. Tillitt, Jr. (Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.): Have any quantitative experiments been done on glass standard leaks? These are considered to be not quite so susceptible to plugging up and gumming up.

R. B. Lawrance: I, personally, have not done any such experiments, preferring to use the oil displacement manometer instead.

(Presented at A.I.Ch.E. French Lick Meeting.)

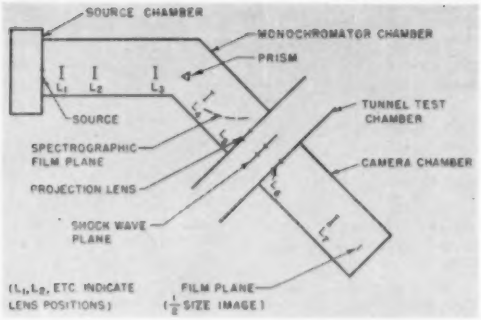


FIG. 1. Left, Diagram of oxygen-absorption flow visualization equipment applied to study of air flow in test chamber of a wind tunnel. Calcium fluoride optics, L indicates lense. *(14)*

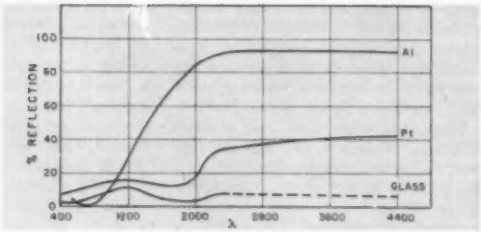


FIG. 2. Above, Reflection characteristics of some materials with ultraviolet light. *(21)*

Flow Visualization in High Vacuums

QUALITATIVE and quantitative knowledge of fluid-flow characteristics in high-vacuum systems obtained from flow-visualization procedures is an important source of information in the understanding and improvement of processes involving fluid-flow phenomena at low-pressure conditions. Flow visualization refers to the various procedures for making all or part of the flow field visible. Several methods of flow visualization at normal pressures have been applied with varying success. As pressures become lower, the common light refraction techniques (shadowgraph, Schlieren, and interferometer) become less sensitive and, in general, are not successful in regions of pressure much below 1 mm. Hg abs. The determination and measurement of pressure and density fields under high-vacuum conditions are developing rapidly. Details and typical results from some of these new techniques are presented in this paper.

The flow-visualization procedure has been used by many investigators for compressible and incompressible fluids in order to study the over-all and detailed characteristics of flow systems. Osborne Reynolds' classical experiments *(1)* included flow visualization in the studies of viscous and turbulent motion of water by using dye as an indicator. Commonly applied flow-visualization techniques for liquids have included small solid particles in suspension where the settling velocity is negligible in magnitude with respect to the fluid velocities *(2)*; small immiscible drops of fluid with dye *(3)*; small air bubbles *(4)*; surface floats of finite size *(5)*, and threads attached to the surface of solid boundaries *(6)*. The procedure of introducing foreign material into the fluid stream for velocity measurements and determinations of general flow paths or streamlines may be applied to gas flows as well as liquid flows. Dust and similar particles have proved effective for the determination of the flow field for gases in motion. In all cases, the introduction of solid particles is subject to two criticisms: first, that the density of the particle is different from that of the fluid, and therefore the particle has a path relative to the path of the fluid resulting in a distorted motion of the solid particles with respect to the fluid, and second, the solid particles may collect at points in the flow system producing a distortion in effective geometrical boundaries. Flow conditions next to a solid surface may vary with time as the surface erodes because of abrasive action of the particles. In spite of these difficulties, many excellent experimental investigations have been accomplished by making use of the qualitative and quantitative information obtained from photographs of particles in suspension in the fluid.

Optical methods for flow visualization depending upon the property of the refraction of light are in common usage for investigations of fluid flow in gases. Problems associated with the slow velocity motions in convective heat-transfer processes and high-velocity phenomena connected with shock waves as well as shock-wave boundary-layer interaction phenomena can be analyzed readily with one or more of the refraction methods. Through modification and perfection, these optical flow-visualization systems have been developed to provide an invaluable tool for studies in the field of fluid dynamics. Unfortunately, the sensitivity of the refraction techniques is limited in the high-vacuum regions.

Due to the minimum pressure limitations for the refraction methods, it becomes desirable to investigate other

R. G. Folsom

R. G. Folsom has been actively engaged in research and consulting work associated with rockets and jet propulsion problems. Under his direction, special equipment has been developed and extensive research investigations undertaken in rarefied gas dynamics. He has been instrumental in establishing the Process Engineering curriculum at Berkeley. Dr. Folsom, chairman, division of mechanical engineering, University of California, Berkeley, since 1949, is the author of more than fifty papers on various aspects of Fluid Mechanics. Early in his career he served as engineer, City of Pasadena, working on cement calorimeter tests. In 1933 he became associated with University of California subsequently accepting the assignment of professor of mechanical engineering.

procedures for flow visualization at high vacuums (pressures in the order of magnitude of 10^{-8} atm. or lower). Many proposals for alternate methods of flow visualization have been suggested; the most important of these are methods utilizing the emissive or absorptive properties of gases. The property of a given kind of molecule to absorb radiation at specific wave lengths or to emit radiation at given wave lengths, when properly excited, forms the basis of possible flow-visualization techniques. The absorption of light or radiation shows promise in applications with oxygen, mercury vapor, and ozone. A review of the emission of light and radiation indicates that the afterglow characteristics of gases are suitable for flow visualization in the high-vacuum regimes. The afterglow of nitrogen, oxygen, and air appear to be satisfactory, at least over a portion of the density range of interest. Development of the afterglow technique is difficult due to the lack of knowledge on details of the phenomena and the large influence of small impurities on the results obtained. The principle of the excitation of an ionized discharge has been used for the development of oil-vapor vacuum pumps and by investigators studying the action of jets in mercury-vapor pumps.

Fluid flows in high-vacuum systems are generally in the viscous-flow region. Even at supersonic velocities the Reynolds number is low enough so that viscous flow exists. For example, in a given flow system with the velocity and the linear dimensions constant and the pressure reduced while the temperature remains of the same order of magnitude, we find that the Reynolds number is reduced because the viscosity remains approximately constant while the density decreases. At high vacuums, the density may decrease by a factor of 10^{-3} or 10^{-4} with respect to atmospheric conditions, and the Reynolds number will be decreased accordingly.

At low Reynolds numbers, thick boundary layers develop rapidly, and it is seldom, if ever, that flow at these conditions approximates a two-dimensional situation. Thus, in many engineering applications, three-dimensional flow exists and it becomes extremely difficult to interpret flow-visualization photographs when this added complication exists. In general, this paper will be restricted to two-dimensional flow and consideration of the interpretation of photographs for three-dimensional flow will be omitted.

Refraction Methods

The refraction methods (*7*) of flow visualization depend upon the physical characteristics of light passing through a density gradient in a gas to be deflected in a manner corresponding to the deflection produced by light transmission through a small-angle prism. A direct comparison of the refraction techniques is difficult since the shadowgraph method depends on the derivative of the density gradient, the Schlieren methods depend on the density gradient, and the Zehnder-Mach interferometer results depend on the density.

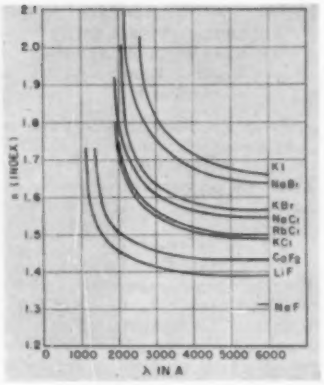


FIG. 3. Index of refraction for materials with ultraviolet light. (*21*)

Shadowgraph Method. The shadowgraph requires the simplest optical system for any method of this classification. The equipment consists essentially of a light source with an optical system, usually a single lense, to produce a parallel light beam which passes through the flow field under investigation and strikes a photometer or photographic film for recording. When the flow field includes a sharp pressure discontinuity like a shock wave in supersonic flow, the characteristic shadowgraph photograph of a three-dimensional flow system shows two lines, a dark line followed by a light line to indicate the discontinuity in the density. In order to develop the performance equation for the shadowgraph it will be assumed that the object concerned has axial symmetry, and the flow includes a shock wave of constant radius R, that L is the distance from the actual center line of the model from the photographic film, and that L_s is the width of the dark line appearing in the photograph and representing the density discontinuity. If one selects suitable magnitudes for the critical geometrical ratios, it is possible to develop a representative performance equation (select reasonable values of $L/L_s = 5000$ and $R/L_s = 333$). The resulting equation (*8*) for the performance coefficient is

$$\frac{\rho_a}{\rho_2 - \rho_1} = \frac{0.000294}{\frac{L_s}{3L}\sqrt{\frac{2}{3}\frac{L_s}{R}}} \qquad (1)$$

where

ρ_a = density at standard atmospheric conditions
ρ_1 = density before discontinuity
ρ_2 = density after discontinuity

Substituting quantities

$$\frac{\rho_a}{\rho_2 - \rho_1} = 100$$

Larger magnitudes of the performance coefficient indicates the ability of the flow-visualization system to distinguish smaller-density discontinuities. Equation (1) is restricted to the type of density discontinuity assumed. For finite density gradients or for geometrical patterns of other than constant radius, a different equation for the performance coefficient will result.

Schlieren Method. Many flow visualization systems have been developed following the general Schlieren method. The optical system is more complex than that used for the shadowgraph, but the interpretation of results is easier. An elementary Schlieren system consists of the light source from which the light passes through a lense, followed by the flow system under observation, and is focused to form an image of the light source; this in turn serves as the source of a second lense which forms an image on the photographic screen. By placing a knife edge at the image point of the light source, it is possible to throw shadows on the photographic plate if the light has been refracted in passing through the fluid field under observation. Assuming a density discontinuity (shock wave) and including practical values for geometrical proportions, a performance coefficient can be obtained for the Schlieren flow visualization system similar to the one presented for the shadowgraph system. The performance coefficient is

$$\frac{\rho_a}{\rho_2 - \rho_1} = \frac{0.000294}{\frac{\Delta I}{I}\tan\theta}\left(\frac{f}{d}\right) \qquad (2)$$

where

$\frac{\Delta I}{I}$ = fractional change in illumination at photographic film
θ = angle of inclination of shock front with optical axis
f = focal length of focusing lense
d = width of light slit (source)

Selecting magnitudes appropriate for measurement of small-density changes

$$\left(\frac{\Delta I}{I} = 0.1,\ \tan\theta = 0.0175,\ \frac{f}{d} = 5000\right)$$

the performance coefficient becomes

$$\rho_a/\rho_2 - \rho_1 = 1425.$$

Equation (2) is limited to the conditions assumed in the derivation. For finite density gradients or different alignment of density gradients with respect to the optical axis of the system, a new equation for the performance coefficient will result.

Interferometer Method. The interferometer (Zehnder-Mach) produces a picture of the flow which can be analyzed directly since density in the photograph depends on the density of the fluid. Essentially the equipment produces two light rays of a given frequency from the same source and causes these rays to traverse paths of the same length but through fluids at different densities; then when the rays are combined a phase relationship will produce alternate light and dark streaks on the photograph. If the two light rays initially cancel each other, then a change in fluid density in the path of one ray will cause a shift in the phase relationship of the two waves (fringe shift), first reinforcing and then canceling and repeating until the full density change is indicated. One fringe shift (dark line through light line to dark line) occurs when the two rays are shifted in phase by one wave length (l) of the incident monochromatic light. The performance coefficient can be developed in the form (9)

$$\frac{\rho_a}{\rho_2 - \rho_1} = \frac{0.000294y}{fl} \qquad (3)$$

where

f = number of fringe shifts
l = wave length of light used
y = length of light path parallel to optical axis

Selecting 0.1 fringe shift as the minimum measurable value and assuming $l = 5000$ A, then with y expressed in inches the performance coefficient becomes

$$\frac{\rho_a}{\rho_2 - \rho_1} = 150y$$

The simple analysis considered here for the development of the performance equation of the interferometer does not include consideration of the possible additional effects produced in regions of very high-density gradients.

Absorption Methods

The absorption method consists essentially of a light source, usually of a single wave length, the light being transmitted through the flow field under investigation to form an image on a photographic film. Light and dark areas will result due to the differences in the intensity of the rays after passing through the portions of the fluid field with different densities. Gases proposed for use with this system have the property of strongly absorbing light of specified frequency. The Lambert equation indicates the relationships above.

$$I = I_o e^{-n\beta y} = I_o e^{-ay} \qquad (4)$$

where

I = intensity of radiation reaching photographic film after passing through absorbing molecules
I_o = intensity of radiation at photographic film with no absorbing molecules in system
n = number of absorbing molecules per unit volume
y = length of absorbing path
β = absorption cross section
a = absorption coefficient

Considering two light paths, 1 and 2, passing through the same gas at different densities,

$$\frac{I_1}{I_2} = e^{(n_2\beta_2 - n_1\beta_1)y} = e^{(a_2 - a_1)y}$$

Since

$$a_1 = \frac{a_a}{\rho_a}\rho_1;\ a_2 = \frac{a_a}{\rho_a}\rho_2$$

the performance coefficient for an absorption system is

$$\frac{\rho_a}{\rho_2 - \rho_1} = \frac{a_a y}{\log_e \frac{I_1}{I_2}} \qquad (5)$$

Investigation of the absorption equations reveals that as the density of the absorbing gas increases the absorption of light becomes so great that no practical detection scheme will be satisfactory for densities greater than a critical value. The absorption coefficient is a function of the frequency of the light used so that for a given gas it may be possible to extend the range of the technique to higher pressures by application of different light sources.

Work in progress at Berkeley is devoted to the oxygen-absorption tech-

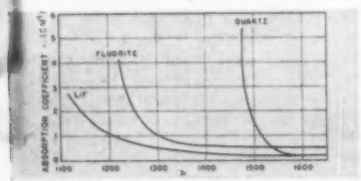


FIG. 4. Above, Absorption coefficients for materials with ultraviolet light. (21)

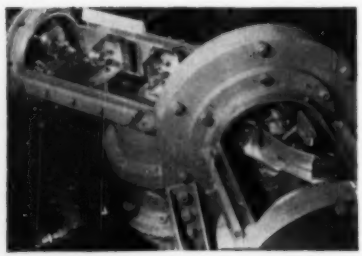


FIG. 5. Left, Photograph of oxygen-absorption equipment with cover removed. Curved piece at right is film holder at spectrographic film plane.

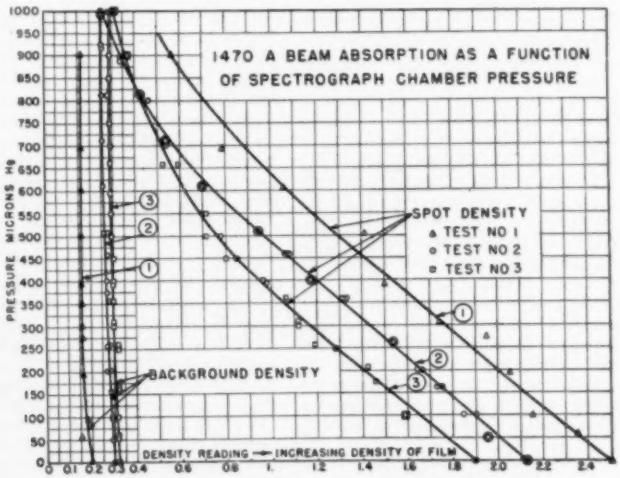
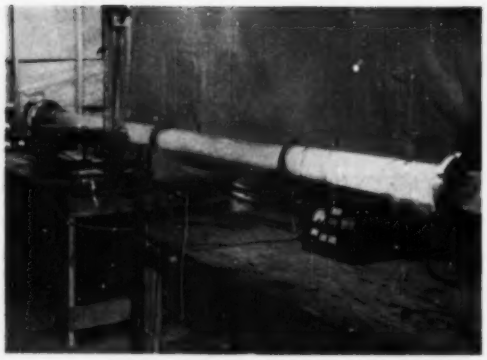

1470 A BEAM ABSORPTION AS A FUNCTION OF SPECTROGRAPH CHAMBER PRESSURE
SPOT DENSITY
▲ TEST NO 1
○ TEST NO 2
▫ TEST NO 3
BACKGROUND DENSITY
PRESSURE MICRONS Hg
DENSITY READING → INCREASING DENSITY OF FILM

FIG. 6. Above, Calibration results for oxygen-absorption system using various pressures in air at room temperatures.



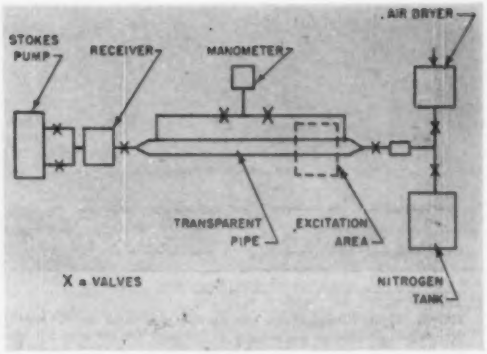


FIG. 7. Photograph of special transparent pipe equipment for investigating nitrogen and air afterglow.

nique, but a summary of other types and comments on applicability is pertinent to the general problem of flow visualization.

Mercury Vapor. Mercury vapor has the property of strongly absorbing 2537 Å wave length light, a frequency which is produced readily in low-pressure mercury arcs. Quartz elements can be used in an optical system using light of this wave length. Due to the lack of suitable published information about the absorption cross section for mercury, approximate measurements have been made over a restricted range of temperatures at atmospheric total pressures. Values (*10*) are tabulated in Table 1.

TABLE 1.—ABSORPTION CROSS SECTION FOR MERCURY VAPOR

T, °F.	β (sq.in.)
80	1.6×10^{-15}
120	4.2×10^{-16}
180	4.7×10^{-17}
220	9.0×10^{-18}

These experiments indicate that a large change of absorption cross section with temperature exists for mercury vapor at room temperature. If this characteristic is indicative of results to be expected at lower temperatures, the light intensity variations in a photograph obtained by the mercury-absorption process may become a better indication of the fluid temperature rather than the density under some flow conditions. The mercury-vapor absorption technique has not been treated completely as it is considered limited in application due to the dangerous and corrosive properties of the vapor and the difficulties associated with the interpretation of the results, especially when considering that the heavy mercury molecule used as a tracer may not determine adequately the flow of the gases being investigated.

Ozone. Ozone has a large absorption coefficient for 2537 Å light; thus it possesses the same advantages as the mercury system with respect to the readily available light source and the simple quartz elements in the optical system. Some information on the magnitude of the absorption coefficients at room temperatures is available in the literature and rough determinations at Berkeley (*10*) verify the general magnitude of these data (with 2537 Å light, $145 < a < 190$). Disadvantages of the method include the problem of producing sufficient quantities of ozone when the flow system under investigation is one of large capacity (storing liquid ozone is hazardous), corrosive properties, and the interpretation of photographs due to the molecular weight of the ozone being appreciably different from that of the surrounding air stream. Low-temperature and low-pressure data on physical properties of ozone are needed before further analyses can be made intelligently regarding the applicability of this technique.

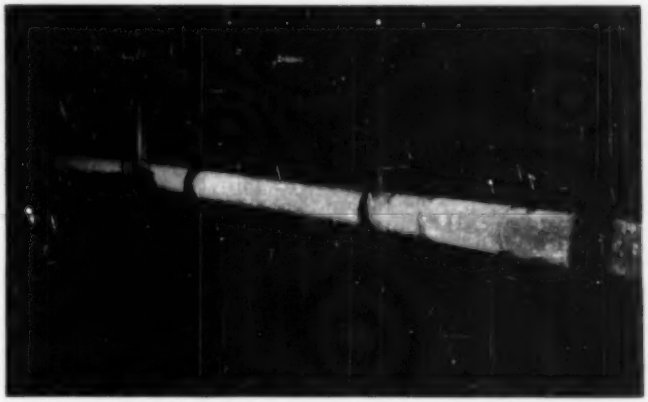


FIG 8. Photograph of air afterglow in pipe equipment shown in Fig. 7.

Oxygen. The oxygen-absorption method utilizes the fact that oxygen has an absorptive capacity which is a maximum at wave length of about 1450 Å. Smaller but still significant magnitudes of absorptive capacities occur in the range of 1300 to 1600 Å. Successful development of this method of flow visualization requires the construction of a suitable light source, an optical system to give parallel and monochromatic light at the fluid test section and a suitable detector. The 1450 Å wave-length light is in the ultraviolet region and is out of the visible range. A diagram of the optical system now under investigation is shown in Figure 1. The source produces light with resonance lines at 1296, 1470, and 4500 Å. The optical system is essentially a vacuum monochrometer to provide 1470 Å light at the projection lense. This latter lense makes the light parallel for transmission through the fluid test section where it then falls on some type of detector. The present detector is a photographic film but a suitable photoelectric cell or fluorescent screen (excited by 1470 Å light and re-

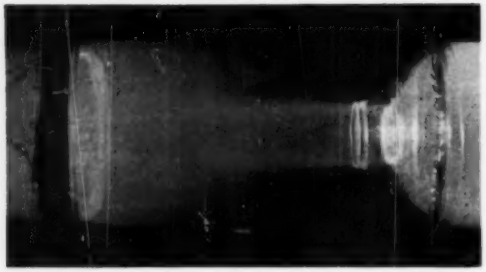


FIG 9a. Right, Nitrogen glow photograph of a shock wave about a 20° half-angle cone at gas velocity of 2.6 times velocity of sound in a pressure of 0.110 mm. Hg. Reynolds number of 530 based on 0.7 in. diam. of cone support.

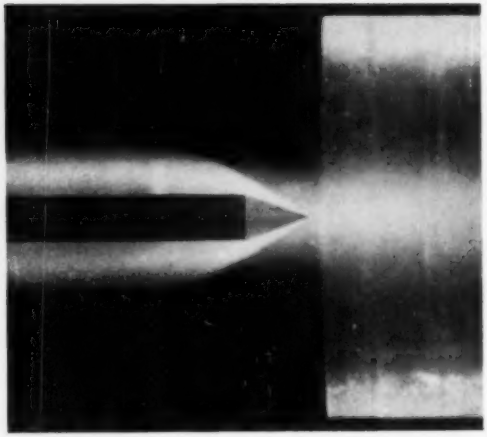


FIG 9b. Above, Nitrogen glow photograph of subsonic flow through a nozzle. Downstream conditions shown.

admitting visible light) might be used.

Since glass, quartz and other transparent materials normally used for optical systems absorb 1470 Å radiation, the elements of the oxygen absorption system must be made from other materials. The difficulties of the problem of selection are indicated by the relationships shown in the curves of Figures 2, 3 and 4. Calcium and lithium fluoride appear to be the only suitable materials readily available. Experience with the grinding of lenses demonstrates that sizes much larger than those of about 1-in. diam. are not practical. Lithium fluoride possesses superior qualities when pure parts are available, but consistent purity is difficult to achieve and calcium fluoride has proved to be more predictable and practical for the optical elements.

For oxygen at atmospheric pressure (29.92 in. Hg) and temperature of 32° F. with light of 1469 Å, the absorption coefficient is 1220 in.$^{-1}$ (*11*). The performance coefficient is obtained from Equation (5) as

$$\frac{p_a}{p_2 - p_1} = \frac{1220y}{\log_e \frac{I_1}{I_2}} \qquad (6)$$

An estimate of performance of this system with air may be obtained on the basis of assumptions that nitrogen and gases other than oxygen absorb no appreciable light and the partial pressure of oxygen is proportional to the number of oxygen molecules, thus

$$\frac{p_a}{p_2 - p_1} = \frac{256y}{\log_e \frac{I_1}{I_2}} \qquad (7)$$

For the investigations at Berkeley the radiation source [see (*12*) and (*13*) for similar units] is a quartz lamp filled with a xenon-neon mixture to a pressure of about 11 mm. Hg (approximately 90% neon and 10% xenon by volume). The lamp consists of two electrodes mounted in tubes which are joined by a small diameter tube (about ¼-in. I.D.). The discharge takes place through the small tube or neck which then becomes the source for the illumination of the optical system. The lamp is sealed off by waxing the lense in place; this lense transmits radiation from the neck of the lamp to the monochrometer portion of the optical system. Before filling with the final gas mixture the tube is thoroughly outgassed in a vacuum furnace to minimize impurities in the form of absorbed vapors or gases. The discharge is struck between the two hot cathodes at a current of 2 to 40 amp. depending on the impedance in series with the lamp and the 220-v. a.c. supply line. The electrodes are constructed from tungsten wire filaments surrounded by a tantalum shield. The energy input to the ½ in. long by ¼-in. diam. tube (source) during operation is almost ½ kw. Of the several wave lengths emitted by the hot excited xenon a characteristic resonant line exits at 1470 Å. Water- and air-cooling of the lamp have been used, but the most recent model submerges the entire lamp in an oil bath which has forced cooling and circulation. The oil is cooled in an external heat exchanger and circulated by means of a gear pump. (*14*)

To produce maximum sensitivity for high-vacuum work, the entire optical system between the source and the projection lense must be in a high vacuum or filled with a nonabsorbing gas. The equipment constructed for this purpose (See Fig. 5) contains an optical bench upon which are mounted the various slits, lenses, and prism required, the whole apparatus being enclosed in a vacuum vessel which can be evacuated to pressures of 10^{-5} mm. of Hg. As a continuous vacuum is maintained through the use of oil-diffusion pumps, there is a tendency for the oil vapors to diffuse back into the optical chamber. Oil films on the optical elements will interfere seriously with the operation of the system and it is necessary to provide refrigerated traps to prevent oil from diffusing into the vacuum spaces. Preliminary calibration work shown in Figure 6 indicates that the transmission characteristics of the optical system are deteriorating with respect to time as the curves were taken in numbered order, the runs being about one week apart. Whether this phenomenon is due to oil vapor collecting on the surface of the optical elements or whether it is a surface action owing to the calcium fluoride being exposed to the 1470 Å radiation is not known at this time. However, it is known that ultraviolet radiation (1470 Å) causes dissociation of oxygen, but for many flow problems it is anticipated that errors due to this phenomenon will be small.

Although no actual flow pictures have been taken with the oxygen-absorption method, quantitative calibrations have been made as indicated in Figure 6. The calibration was accomplished by operating the source in the usual manner and controlling the pressure in the optical case at approximately constant room temperatures. A film placed in the region of the projection lense will record the light transmitted through the optical system at various densities of air. The intensity of the photographic film was measured with a Weston densitometer with scale readings proportional to

$$\log_e \frac{I_o}{I_1}$$

The film was Eastman 103-0 type sensitized for the ultraviolet region (film coated with special fluorescent material which re-emits visible light when excited with ultraviolet radiation). Processing of the film includes removing the fluorescent coating and normal developing procedures with D-19 developer. Two readings were obtained with the densitometer, one on the spot representing the intensity of the light transmitted and the other the intensity of the background. Both values are plotted in Figure 6, for three runs. The length of the absorption path is approximately 35 in. Additional work with different exposure times is necessary to explore fully the capabilities of this system. The straight line portions of the curves of Figure 6 correspond to the characteristics predicted for absorption with air by Equation (7) except the constant is 236, a magnitude about 8% lower than the predicted value.

Experimental work with the oxygen-absorption system is being continued as the method presents the optimum possibilities of obtaining quantitative density data at low-pressure conditions. The afterglow and the electrical-discharge procedures to be described will work at lower pressures still but they are quali-

tative in nature and quantitative results will be extremely difficult or impossible. It should be noted that if the flow field is small enough so that a picture of the complete field can be obtained within the limitations imposed by the calcium-fluoride optical elements, readings from the densitometer will give an analysis of the densities at any corresponding point in the flow field. In the event that a large field is to be investigated, it will be necessary to scan the region involved.

X-rays. Soft X-rays may be used in the absorption process for flow visualization. Preliminary experiments have used effective wave lengths in the neighborhood of 4 Å and actual flow system surveys have been completed (*15, 16, 17*). The systems and the results obtained will not be discussed in detail here since the oxygen-absorption method, the nitrogen and air-afterglow techniques will operate at pressures considerably below the lowest pressure for application of the X-ray method.

Glow Method

An electrical discharge through a gas between electrodes arranged in suitable positions provides a practical method of flow visualization. Qualitative information about the fluid flow is readily attainable and the illumination has been sufficient to take motion pictures of shock waves about simple objects in a supersonic air or nitrogen stream at absolute pressures in the order of 40μ of Hg. The method has limited applicability since the discharge between the electrodes tends to produce striation in the flow and it is not always possible to have these striations in the vicinity of the phenomena under investigation. In addition, the ionized particles produced in the discharge are influenced by the electric and flow fields.

When nitrogen, oxygen, air, and other gases are properly excited, they produce an afterglow or radiation which persists for some time after the excitation is removed. This afterglow has proved valuable for flow visualization since the illumination may persist during the time the fluid is passing through the flow system. If the system is constructed of transparent material, it is possible to obtain qualitative information regarding the density and density distributions from an observation of the resulting intensity of illumination. Investigation of the afterglow phenomena and flow visualization at high-vacuum conditions is being followed actively by Kaplan (*22*), Benson (*18*), and Kunkel (*19*). Investigations to date have demonstrated that the afterglow for nitrogen and air provides suitable techniques for fluid-flow studies.

The mechanism of the phenomena producing the afterglow is not well understood. Several workers in physics are studying nitrogen afterglow, the work being associated with development of knowledge about the physics of the upper atmosphere. Similar investigations are being made with air (*20*) where spectroscopic results are taken as strong evidence that the afterglow is due to chemilluminescence caused by reactions between oxides of nitrogen and ozone. Due to the present lack of knowledge about the phenomena, it has been necessary to develop the afterglow flow visualization technique by a trial-and-error procedure.

At Berkeley, special laboratory apparatus was constructed to investigate the nitrogen and air-afterglow characteristics. A separate vacuum flow system was established in a 6-in. diam. transparent pipe, approximately 20 ft. long. Gas (bottled nitrogen or dry air) was introduced into one end of the pipe and removed from the opposite end by a mechanical pump. Velocities below 50 ft./sec. were achieved for static pressures in the region of 5 mm. Hg. The electrodes or electrical-discharge system was installed just downstream from the entrance to the pipe. Due to the magnitude of the energy released at the electrodes and the relatively high temperatures created, the transparent pipe in the vicinity of the discharge was made of glass, the remainder of the pipe being lucite. Many electrical-excitation schemes and electrode-geometrical arrangements were tried. Table 2 summarizes the variables and the range of afterglow tests in the special laboratory glow equipment, and in a special low-pressure high-velocity wind tunnel.

When using radio-frequency excitation, it is possible to pulse the discharge to demonstrate the afterglow characteristics. If the nitrogen or air flow is established through the pipe and excitation is applied, the pipe (which is installed in a dark room) will be filled with a luminous gas. The electrical discharge in nitrogen is bright white to yellow in color and immediately outside of the discharge region the glowing gas is orange. The rest of the pipe shows the characteristic afterglow which is illustrated by suddenly interrupting the electrical circuit. In this case, the discharge glow disappears and the observer can follow the motion of the rear of the afterglow region down the pipe. Likewise, when the electrical discharge is turned on, the front of the afterglow region proceeds down the pipe. Figure 7 shows the special flow visualization pipe and its associated equipment as installed in the dark room. Figure 8 shows the same pipe when afterglow is taking place and the room is completely dark.

Observation of the nitrogen afterglow in this special equipment reveals that the phenomena appear to have different characteristics in the region immediately downstream from the discharge and at greater distances downstream. When using nitrogen as the gas, the first three to seven feet of the pipe show an illumination in the orange-green range which is more intense than the illumination in the yellow-green (Lewis-Rayleigh afterglow) of the downstream portions of the pipe. There appears to be a region of discontinuity giving rise to the supposition that two or more types of nitrogen afterglow are possible. A satisfactory explanation does not exist but experiments are in process to determine the difference in these characteristics. It should be noted that it is difficult to obtain satisfactory spectrograms since the intensity of the illumination is low and it is not possible to have the electrical discharge system on for more than a short time since the temperature will rise in the glass and mechanical failure

TABLE 2

Electrode Arrangement	Gas Tested	Excitation Power	Voltage	Current	Pressure Level: Glow	Pressure Level: Observation	Remarks
Grid upstream to Ground ring downstream (across flow area)	N_2	60 cycles ac.	0–80 v.	10–50 ma.	4 mm.	100 μ	Discloses no deionizing (*WT)
Anode to grid	N_2 & Air	60 cycles ac. & dc.	0–80 v. 500 v.	10–50 ma. 100–300 ma.	4 mm.	100 μ	Partially deionized (WT)
Anode to cathode with screens further downstream	N_2 & Air	dc.	500 v.	100–700 ma.	2 to 40 mm.	2 to 40 mm.	Tests in pipe and (WT)
Cross stream electrodes	N_2 & Air	60 cycles ac.	500 v. to 2000 v.	0.5 to 8.0 amp.	1 to 5 mm.	20 to 100 μ	Shock tests (WT)
No electrodes in stream Oscillator around pipe	N_2 & Air	40 megacycles ac.	Power input to oscillator from ½ to 2½ kw. 30% loss in oscillator		2 to 10 mm.	2 to 10 mm.	Tests in pipe

* *WT* indicates tests made in wind tunnel where discharge is at one pressure and flow visualization at a lower pressure. All wind-tunnel tests were made with velocities greater than the velocity of sound.

may result. Preliminary observations have indicated that both nitrogen afterglows possess a band spectra. When the experiments are repeated using air as the gas, the intensity increases, the color changes to blue-green and the spectrogram is continuous.

Analysis of photographs (Fig. 9) obtained in the pipe and in the special wind tunnel indicates that the flow characteristics are made visible through the combined action of the electrical discharge and the afterglow phenomena. Studies reveal that these photographs are possibly not of the nitrogen or air afterglow alone. To date no pictures have been taken at Berkeley using the afterglow phenomena exclusively, although Benson (*18*) has reported pictures which were taken in the nitrogen afterglow. The complexities of the equipment, the combination of the different afterglows with the electrical discharge, as well as the purity of the gases concerned, make investigation by a trial-and-error procedure a difficult undertaking. Progress has been achieved as indicated by the photographs in Figure 9.

Additional investigations with the afterglow phenomena are important since this technique has the possibility of showing flow characteristics at lower pressures than any of the other techniques proposed. On the other hand, considerable development remains to be done including comparison of flow visualization by afterglow with that obtained by more normal or conventional procedures. As an example, it may be necessary to consider preparation of all surfaces concerned as observations in the special flow pipe have shown that considerable surface-quenching occurs.

Comparison

A direct comparison of the various refractive, absorption, and glow methods of flow visualization in high vacuums is impossible on a generalized basis. When a given situation is specified, such as the necessary pressure difference, the length of the path and similar fixed requirements, it is possible to develop a chart which shows the general applicability and lower limits of these systems of flow visualization. In order to provide an approximate comparison, the constant of the performance equations has been gathered together for presentation in Table 3. The shadowgraph and Schlieren techniques apparently are independent of the length of the light path. This, of course, is not correct because the length characteristic has been included when a magnitude was assumed for length ratios for substitution in the fundamental equation. In the event that a given installation is specified completely, the appropriate performance coefficients may be calculated and different techniques compared directly. It should be noted that the greater the magnitude of the constant, the more sensitive the system, or the lower the absolute pressure at which a given pressure difference can be shown.

TABLE 3

		Performance Coefficient
Shadowgraph		100
Schlieren		1425
Interferometer		150y
Mercury vapor	Absorption	...
Ozone	Absorption	420y*
Oxygen	Absorption	1220y*
Air	Absorption	256y*
Nitrogen Afterglow	Unknown	(>1220y)
Air Afterglow	Unknown	(>1220y)

* Based on assumed value of $\log_e \frac{I_1}{I_2} = 0.1$.

y in inches.

Acknowledgments

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Discussion

E. L. Piret (University of Minnesota, Minneapolis, Minn.): What is the half-life time on this sort of radiation effect—very long or very short?

R. G. Folsom: The various afterglows investigated at the University of California do not have an exponential decay; therefore, the normal half-life description does not apply. We have, however, visually observed the glow to determine the persistence of the luminosity for our wind-tunnel work. The Lewis-Rayleigh afterglow appears to persist the longest, being visible for from 3 to 10 sec. after the discharge. The air glow is visible for at least 1 sec. beyond the excitation region, while the "short life" afterglow is only visible for approximately 1/10 sec. These observations were taken in a system with a pressure of the order of 3 mm. Hg and it is to be expected that the persistence of the glow would be longer at reduced pressures.

E. L. Piret: Are there any thermal or re-radiation effects which would tend to distort the results?

R. G. Folsom: Various thermal and secondary emission effects are known to occur when using the afterglow flow visualization technique. The rise of temperature within the gas, due to the discharge, is probably quite small. What is more important is a high energy level of the metastable particles which is of the order of 6 to 9 electron v. These metastables will bombard any model or probe placed in the stream, thereby heating the model. This heating may visibly affect the flow about the model. It is doubtful, however, that the secondary emission would affect the flow visualization. The entire problem of distortion of the results is still open to experimental investigations.

EFFECT OF COLUMN HOLDUP AND REFLUX RATIO

In Binary Batch Distillation

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ANY batch distillation may be divided into (1) a startup period prior to removal of any distillate, and (2) the distillation proper, i.e., the period after which distillate removal is commenced. Both phases of the operation are complex, and existing publications on the subject leave much to be desired for practical predictions. The phenomena of the preliminary period have been discussed by Berg and James (*1*), Coulson (*4*), and Cottrell (*3*). The present paper deals with the period of the distillation proper. Over-all evaluation of any specific batch-distillation problem requires a combination of the conclusions for each of the two distinct phases of the process. Results are best discussed in terms of the shape of curves relating instantaneous product composition and per cent of charge distilled.

Significance. Undoubtedly, the greatest potential application is in multicomponent distillation. It is particularly significant that the first systematic study of ternary batch fractionation (*8*) clearly indicated that sharpness of separation of any two components was governed by the per cent holdup based upon the absolute amount of these two components in the initial ternary charge. Since two components may constitute a small portion of a ternary charge, large effective holdup and consequent large effects on separation can be expected to be regularly present in multicomponent batch distillation, even though holdup is small compared with total charge.

General Procedure

The main contents of this paper are the results of a series of actual batch distillations in a five-plate column, with variations in reflux ratio, charge composition, and charge size (and thus holdup/charge ratio). These factors are varied over and beyond the entire range of practical interest. The results are summarized on a single graph to show for the first time the favorable and unfavorable effects for all the combinations of the variables for distillation with a particular column and mixture.

Theoretical calculations are made also for circumstances similar to those of the experiments. The same conclusions are reached from the calculations and from the experiments, and these are both in accord with the trends shown in less complete experiments in columns with a larger number of plates. It would, however, be unwise to expect distillation in many plate columns to show more than an agreement in the trends with the results of the five-plate experiments. Specific separations are determined by the complex interrelations between the variables.

Methods of calculation are suitable for prediction of the effect of operating variables for specific practical cases. The actual computational procedures have already been published (*12, 13*). A companion paper to the present one describes the mathematical basis for the calculations, including particularly the extension to practical cases.

Use of constant reflux ratio throughout a particular distillation in the experiments and calculations of the present paper may require special justification in view of the soundly established practice of using low reflux along the plateaus of a distillation curve and high reflux at the breaks. First, it must be recognized that achievement of the desired separation or purity along a plateau is so simple and easy a matter that it is hardly worth a detailed study. The real problems come at the break in the distillation curves when the intermediate fraction or slop cut is being produced. For this reason research work on batch distillation consists mostly of a study of the factors operating during formation of intermediate fractions. Of course, the practical man might still say that reflux ratios are often changed several times during the formation of a particular slop cut. However, it is logically impossible to approach the problem of prediction without breaking down such a process into the several periods during which reflux ratio is constant. The same may be said about a constantly changing reflux ratio that produces constant distillate composition. Until the effect of one particular reflux ratio is understood, it is impossible to predict what a combination of several will do.

Finally, there is the practical matter of actually performing the research.

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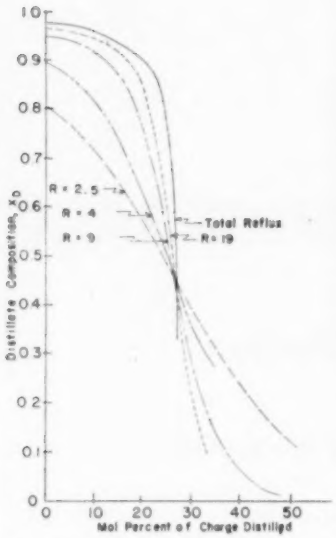

Fig. 1. Distillate composition vs. mole per cent of charge distilled.

Theoretical curves
Holdup: Zero
α: 2.23
Charge composition: 0.250
Five plates and still pot

The experimental and theoretical problems for constant reflux are sufficiently challenging, so that it would seem wise to clarify this before proposing to enter into the more highly complicated multiple reflux ratio problem. Once the single constant reflux ratio problem is solved, the multiple case becomes relatively simple. For all these reasons the present paper considers only constant reflux for any particular distillation.

Historical Development. During the past ten years a considerable amount of work has been done in an attempt to determine the effects of the operating variables in batch distillation. Many of the results, particularly those obtained in the study of column holdup, have been contradictory.

Smoker and Rose (*18*) showed close agreement between experimental curves, obtained with holdup of approximately 2%, and calculated curves based on zero holdup. In the calculated curves it was assumed that the still pot and product compositions could be found by the McCabe-Thiele procedure.

Colburn and Stearns (*2*) presented results of experimental work done on a 15-plate bubble-cap column, using ethylene dichloride and toluene as a test mixture, with holdup in the range of 20 to 30%. When the experimental results were compared with calculated zero-holdup curves, it was found that column holdup was beneficial (i.e., it gave a sharper break in the distillation curve), and that this was especially true for low reflux ratios.

Houston (*5*) compared various experimental curves with one another. He found, in columns of 13 and 20 plates, with reflux ratios of from 3.5 to 40, that increasing holdup either had no effect, or that it was beneficial to the separation. O'Brien (*7*) observed, in columns of about 100 plates, and holdup in the range of 0 to 25%, that the experimental curves always broke more sharply than calculated zero-holdup curves. He also concluded that calculations based on zero holdup represented the most practical method of predicting curves when holdup was less than about 5%.

The most comprehensive observations were made by Prevost (*10, 16*) who found that holdup could be detrimental or beneficial, or that it could have no effect on the sharpness of separation. He proposed that a critical reflux ratio exists for each mixture and column, such that change in holdup has negligible effect on the sharpness of separation. At higher reflux ratios increased holdup is detrimental; at lower reflux ratios it is beneficial. He also speculated that a similar situation exists for relative volatility and initial composition. In addition, he noted that curves for large holdup were insensitive to reflux ratio.

In each of these series of experiments, as well as those of this paper, the per cent of holdup was varied by changing the charge size rather than the absolute amount of holdup.

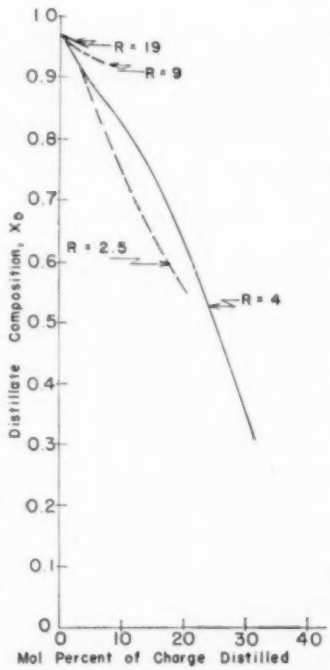

Fig. 2. Distillate composition vs. mole per cent of charge distilled.

Theoretical curves
Holdup: 7.2% of charge
α: 2.23
Charge composition: 0.250
Five plates and still pot

Several theoretical investigations have also been made. The first work involved the assumptions of negligible holdup and total reflux, and the resulting predictions were therefore restricted to limiting cases (*14*). The differential equations for batch distillation with appreciable holdup and finite reflux (*2, 11*) have not been converted to a form that is useful for definite predictions. Even numerical approximation methods (*6*) and differential analyzers (*9*) have been of limited value for predicting the course of a batch distillation because of the form of the differential equations.

The most recent work has been concerned with the stepwise numerical solution of finite difference equations used to approximate the differential equations. Preliminary results of some of this work, done on a desk calculator, were given in a recent paper (*12*). Calculated and experimental curves showed sufficient similarity to prompt continued study.

Calculation of Theoretical Curves. The method of calculation was the same as that outlined in the above-mentioned reference (*12*) except that an IBM punched-card computer was used for the actual computations. The programing is described in detail by Williams (*19*) and summarized in the paper by Rose and Williams (*15*). All calculations were made for a column consisting of five plates and a still pot, a mixture of ethylene dichloride and toluene ($\alpha = 2.23$), and a charge composition of 25 mole % ethylene dichloride. Calculations were made for reflux ratios of 2.5, 4, 9, and 19, and holdup was varied from approximately 1 to 60%.

The basic equation in all the calculations is the finite difference equivalent of the differential equation representing the material balance around a plate. This is most conveniently written

$$Hx_{n,(t+1)} = Hx_{n,t} + (Vy_{(n-1),t} + Lx_{n+1,t} - Vy_{n,t} - Lx_{n,t}) \quad (1)$$

This gives the moles of the more volatile component left on the plate at the end of a short interval of time ($Hx_{n,(t+1)}$) in terms of the moles present at the beginning of this interval ($Hx_{n,t}$) and the quantities entering and leaving the plate. There is one such equation for each plate, those for the top plate and still being of slightly different form. All quantities on the right are known or can be determined at the time of startup, so that values of $Hx_{n(t+1)}$ at the end of the first interval of time can be computed directly, and thus $x_{n(t+1)}$ can be obtained by dividing by H, and $y_{n,t+1}$ from vapor-liquid equilibrium relations. These then may be used in a repetition of the calculation, and so on.

Experimental Equipment and Procedure. A five-plate column with a test mixture of ethylene dichloride and toluene was used also for the experimental work. The column consisted of five bubble-cap plates, of 2 in. diam., with a plate spacing of 6 in. Provisions were made for automatically keeping the column adiabatic, and for heating the reflux. Vapor and liquid samplers were located on each plate. Auto-

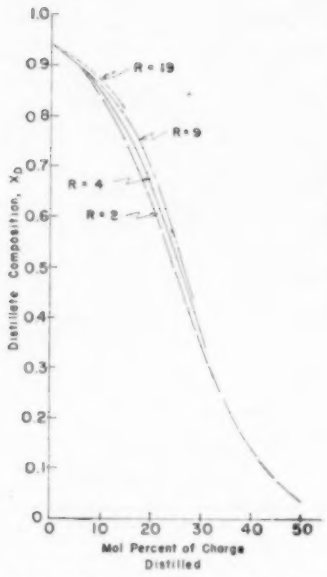

Fig. 3. Distillate composition vs. mole per cent of charge distilled.

Theoretical curves
Holdup: 28.8% of charge
α: 2.23
Charge composition: 0.250
Five plates and still pot

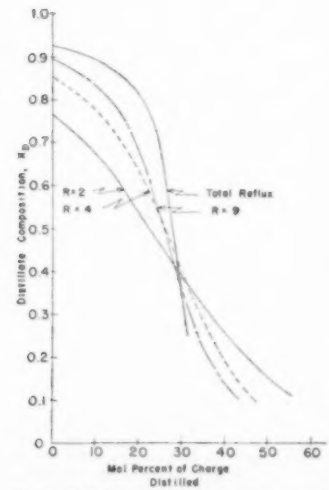

Fig. 5. Distillate composition vs. mole per cent of charge distilled

Calculated curves
Based on experimental x_D vs. x_r relationships
Holdup: Zero
Charge composition: 0.254

matic pressure and throughput controls were used in order to eliminate any effects due to changes in these variables. A system of thermocouples and an automatic temperature controller and recorder made possible a close check on adiabaticity and composition changes on the plates.

On this column 35 runs were made. The holdup was varied from approximately 4 to 40% of the charge. Charge compositions of 10, 25, and 50 mole % ethylene dichloride and reflux ratios of 2, 4, and 9 were studied. The column was always allowed to come to equilibrium at total reflux before take-off was commenced. The column was judged to be at equilibrium when the temperature recorder and thermocouple readings no longer changed with time.

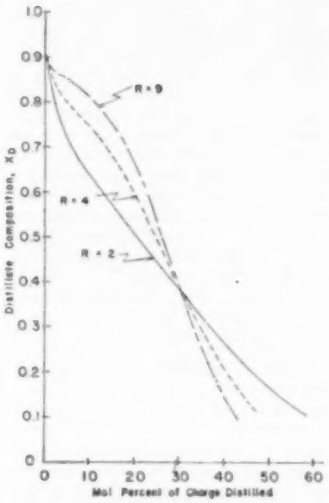

Fig. 6. Distillate composition vs. mole per cent of charge distilled.

Charge: 8000 g.
Holdup: Approximately 4.1%
Charge composition (x_c): 0.254

Run No.	Reflux Ratio	Legend
34	2	———
33	4	– – – –
30	9	— — — —

Results

Effect of Reflux Ratio. The theoretical curves of product composition *vs.* per cent of charge distilled are presented in Figures 1-4. On each individual figure the holdup is constant and the reflux ratio is the parameter. The curves differ most from each other when zero holdup is assumed. As holdup is increased, the reflux ratio has less and less influence on the course of the distillation. At 57.6% holdup (Fig. 4) the curves are practically identical.

It should be noted that the curves in each set (for a given holdup) start at

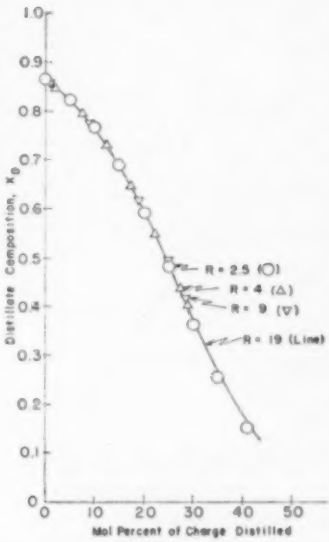

Fig. 4. Distillate composition vs. mole per cent of charge distilled.

Theoretical curves
Holdup: 57.6% of charge
α: 2.23
Charge composition: 0.250
Five plates and still pot

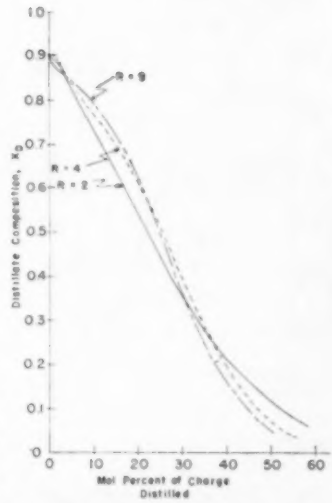

Fig. 7. Distillate composition vs. mole per cent of charge distilled.

Charge: 2000 g.
Holdup: Approximately 16%
Charge composition (x_c): 0.254

Run No.	Reflux Ratio	Legend
24	2	———
8	4	– – – –
21	9	— — — —

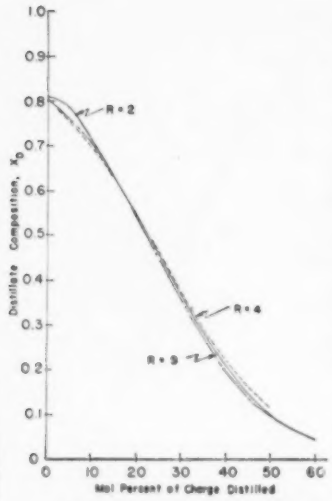

Fig. 8. Distillate composition vs. mole per cent of charge distilled.

Charge: 750 g.
Holdup: Approximately 40%
Charge composition (x_c): 0.254

Run No.	Reflux Ratio	Legend
14	2	———
6	4	– – – –
13	9	— — —

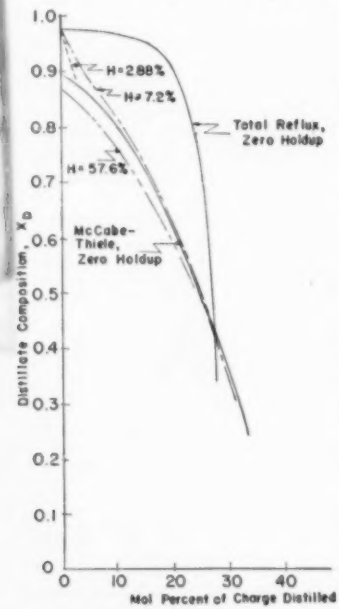

Fig. 10. Distillate composition vs. mole per cent of charge distilled.

Theoretical curves
Reflux ratio: 4/1
α: 2.23
Charge composition: 0.250
Five plates and still pot

the same point, except for the case of zero holdup (Fig. 1). This last case is not entirely comparable because zero holdup is an imaginary condition. Curves for a finite but small holdup would start at a common point and then drop almost vertically so as to appear identical with the curves of Figure 1.

Figures 5-8 show experimental curves, arranged in order of increasing holdup (decreasing charge) for 25% charge composition. Again it is evident that, as holdup increases, reflux ratio has progressively less influence on the course of the distillation. This was also found true with the 10% charge composition. Further results of this kind are summarized in Figures 22 and 23.

Again, the zero holdup curves are not strictly comparable with the others, since they obviously cannot be determined directly. They could be obtained by extrapolation of the other holdup curves, but instead the following procedure was used. Values of still and distillate compositions that correspond to negligible holdup were determined by a series of column experiments in which the desired reflux ratio was set, but the distillate was returned directly to the still, and operation continued until a steady state was reached. The resulting still distillate composition curves were then used in the Rayleigh equation to obtain the zero holdup curves.

Effect of Holdup. In this section the curves have been replotted with reflux ratio held constant and holdup as the parameter. Theoretical curves are shown in Figures 9-12. Some of the intermediate curves have been omitted for greater clarity. Figure 12 is an enlargement of the initial portions of the curves for reflux ratios 9 and 19.

The same effect of holdup is evident in every case. As holdup decreases, the initial composition approaches more closely the initial composition for zero holdup. However, as the distillation progresses, the curve tends to approach the curve calculated for zero holdup, i.e., the McCabe-Thiele zero-holdup line. The less the holdup, the more closely the main part of the curve tends to follow this zero-holdup line.

The experimental curves for charge composition of 25% are given in Figures 13-15, and for charge composition of 10% in Figures 16-18. Again, it is evident that the lower the holdup (higher charge) the more the curve tends to follow the zero-holdup curve. This occurs with all charge compositions and reflux ratios. In many cases, the low-holdup curve crosses all the other curves and falls below the zero-holdup curve. This occurs to a greater extent, in general, with low charge compositions

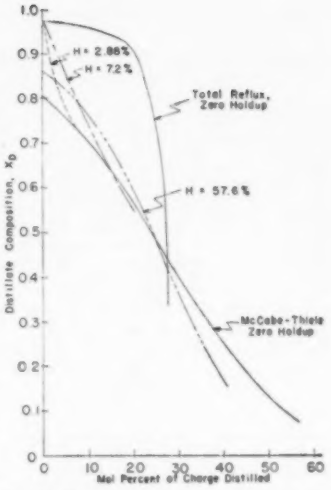

Fig. 9. Distillate composition vs. mole per cent of charge distilled.

Theoretical curves
Reflux ratio: 2.5/1
α: 2.23
Charge composition: 0.250
Five plates and still pot

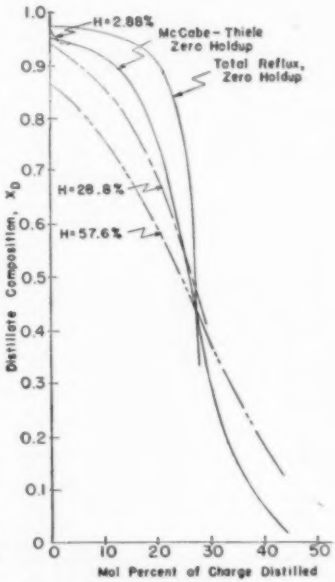

Fig. 11. Distillate composition vs. mole per cent of charge distilled.

Theoretical curves
Reflux ratio: 9/1
α: 2.23
Charge composition: 0.250
Five plates and still pot

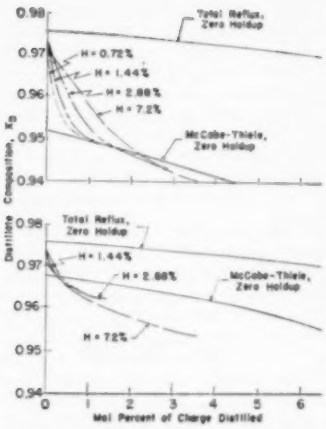

Fig. 12. Distilled composition vs. mole per cent of charge distilled.

Theoretical curves
Reflux ratio: 19/1 (upper graph), 9/1 (lower graph)
α: 2.23
Charge composition: 0.250
Five plates and still pot

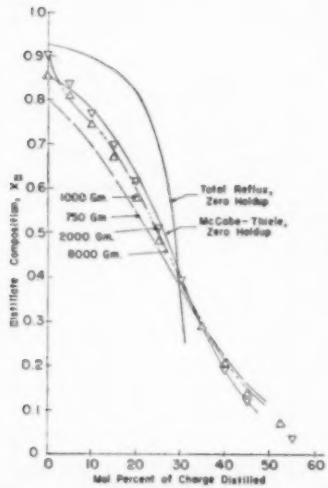

Fig. 14. Distillate composition vs. mole per cent of charge distilled.

Reflux ratio: 4/1
Charge composition (x_c): 0.254

Run No.	Charge, g.	Legend
6	750	
7	1000	
8	2000	
32	8000	

and reflux ratios, because the experimental curve starts at a much higher point than the zero-holdup curve. To maintain the material balance, it must fall below the calculated curve for at least part of the distillation.

Comparison of Calculated and Experimental Curves. No attempt was made in these calculations to take into account the various types of non-ideality inherent in the experimental distillations. As a consequence, it is not possible to superimpose any of the calculated curves on corresponding experimental curves. However, it was noted that the experimental plate efficiency of 74% was apparently the major cause of discrepancy. A more recent series of calculations (*13*) has been made for 74% plate efficiency, and these show good agreement with the corresponding experimental curves.

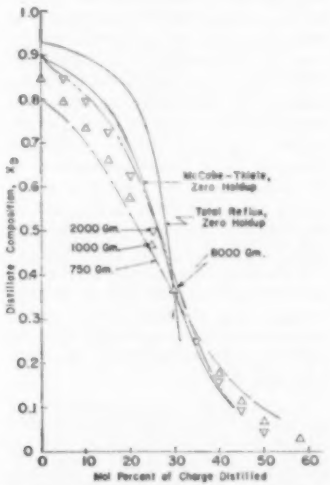

Fig. 15. Distillate composition vs. mole per cent of charge distilled.

Reflux ratio: 9/1
Charge composition (x_c): 0.254

Run No.	Charge, g.	Legend
13	750	
12	1000	
21	2000	
30	8000	

Distillate Composition vs. Still Pot Composition. In Figures 19-21 values of x_D are plotted *vs.* x_s for the experimental runs with charge composition of 25%. These curves and those for charge compositions of 10 and 50% show the same relationships as the theoretical curves reported in Rose, Johnson, and Williams (*12*) and the experimental curves of Prevost (*10*). Briefly, the relationship is this: as the holdup is in-

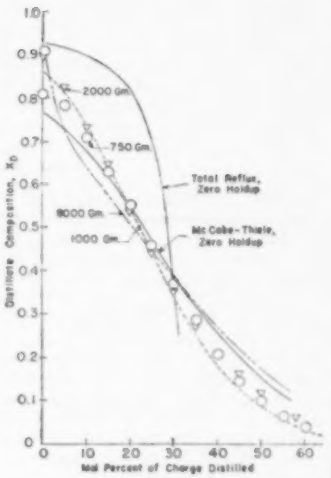

Fig. 13. Distillate composition vs. mole per cent of charge distilled

Reflux ratio: 2/1
Charge composition (x_c): 0.254

Run No.	Charge, g.	Legend
14	750	
15	1000	
24	2000	
34	8000	

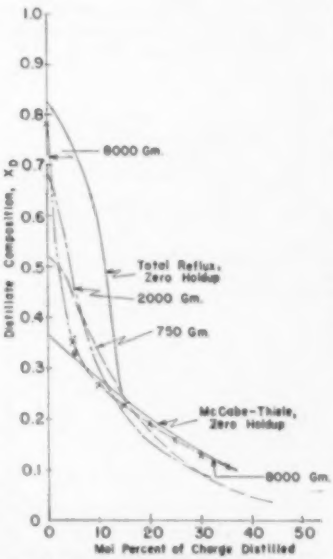

Fig. 16. Distillate composition vs. mole per cent of charge distilled.

Reflux ratio: 2/1
Charge composition (x_c): 0.101

Run No.	Charge, g.	Legend
16	750	
25	2000	
28	8000	

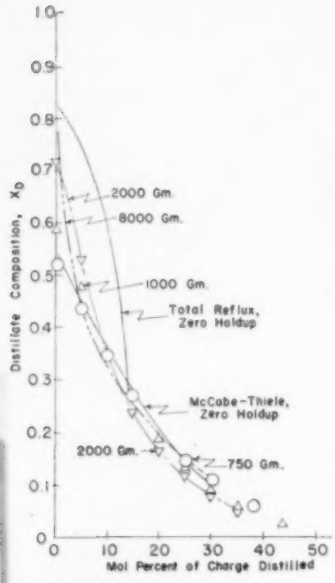

Fig. 17. Distillate composition vs. mole per cent of charge distilled.

Reflux ratio: 4/1
Charge composition (x_c): 0.101

Run No.	Charge, g.	Legend
9	750	○
10	1000	△
11	2000	▽
27	8000	——

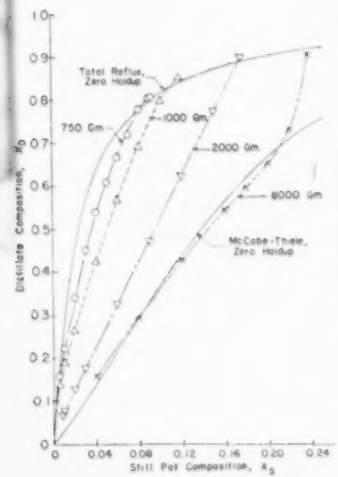

Fig. 19. Distillate composition vs. still pot composition.

Reflux ratio: 2/1
Charge composition (x_c): 0.254

Run No.	Charge, g.	Legend
14	750	○
15	1000	△
24	2000	▽
34	8000	×

creased, the x_D *vs.* x_s curve approaches the total reflux line; as the holdup is lowered, the x_D *vs.* x_s curve approaches the McCabe-Thiele line.

In some cases the high-holdup curve tends to cross and lie above the total reflux line, thus implying that the operating line may fall below the diagonal. In many cases the low-holdup line falls below the McCabe-Thiele line for a portion of the distillation. This effect is probably caused by total reflux start-up.

In only one case (Fig. 20) in this present experimental work was there any crossing of the x_D *vs.* x_s curves. In all other cases, the less the holdup, the less was the spread between x_D and x_s.

Results in Condensed Form. It is often difficult to compare distillation curves as such. Consequently, various indices have been proposed which make it possible to express a curve as a single number or quantity. In this work the different curves were compared by taking the average product composition at 80% of the nominal cut point as a measure of the sharpness of separation. (The nominal cut point is defined as the point in the distillation when the quantity of distillate removed is equal to the quantity of more volatile component charged.) This allows presentation of all the results of the theoretical calculations on one graph (Fig. 22), and all the results of the experimental distillations on one other graph (Fig. 23).

If the terms beneficial and detrimental are interpreted to mean that the average composition at the 80% point is raised or lowered by increased holdup, then the following observations may be made from Fig. 22.

At high reflux ratio increased holdup is detrimental. (Not enough points are available on the line for $R = 19$ to show its exact course.) As reflux ratio is decreased the sharpness of separation has more and more of a tendency to start at a relatively low point with low holdup, rise to a maximum, and thereafter decrease as holdup increases. A rather large holdup (15 to 30%) is necessary for the highest degree of separation at the low reflux ratios.

At very high values of holdup the reflux ratio has little influence on the sharpness of separation. Actually, it appears that a low reflux ratio is better, but the difference is small.

In addition to verifying the above, the experimental curves (Fig. 23) lead to additional observations:

The effect of reflux ratio is much more pronounced at low values of product composition. In the present work the lower product composition was caused by lower charge composition. This suggests that the chief reason for the beneficial effect of holdup is the total reflux startup that is an integral part of all conventional batch-distillation operations. It is conceivable that the same results would be obtained with a higher charge composition but lower relative volatility or lower separating power of the column.

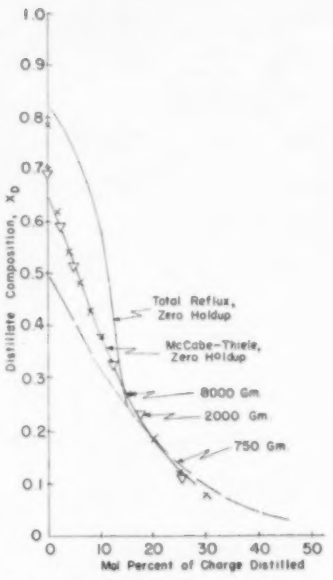

Fig. 18. Distillate composition vs. mole per cent of charge distilled.

Reflux ratio: 9/1
Charge composition (x_c): 0.101

Run No.	Charge, g.	Legend
17	750	▽
23	2000	▽
26	8000	×

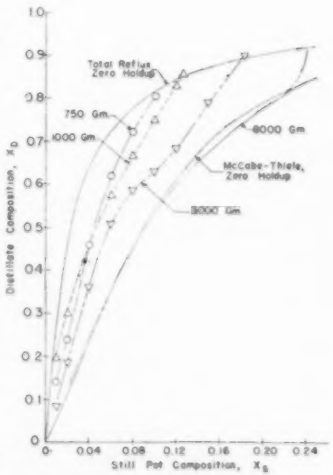

Fig. 20. Distillate composition vs. still pot composition.

Reflux ratio: 4/1
Charge composition (x_c): 0.254

Run No.	Charge, g.	Legend
6	750	○
7	1000	△
8	2000	▽
33	8000	×

Explanation of Results of Earlier Workers. A study of the above figures reveals that all the contradictory conclusions reached by previous investigators could be made here also, if the ranges of variables considered were not sufficient. It is possible to choose ranges of values of reflux ratio, holdup, and charge composition to conclude that holdup has any desired effect.

Prediction of Distillation Curves and Choice of Optimum Operating Conditions. It is difficult to predict the distillation curve for a given mixture in a given column, or to state how a column should be operated to achieve a desired degree of separation.

The finite difference method of calculation can be used to predict the distillation curves for a particular mixture and column, and to predict advantageous operating conditions for a specific case.

When these detailed calculations are not justified, the following procedure serves to give a first approximation to the desired results:

The total reflux zero-holdup (Rayleigh) curve can be calculated, by the method outlined by Rose and Welshans (*14*), for a given column and mixture. From this curve it can be immediately determined whether the column is capable of performing the desired separation under the best possible conditions. If not, no further study need be made for this column and mixture.

If the total reflux curve shows that the column can be used, the McCabe-Thiele zero-holdup curves can be calculated for various reflux ratios which seem suitable for the given column, desired capacity, etc. The method is outlined by Smoker and Rose (*18*). If possible, experimental values of still pot and product compositions, obtained by equilibrium operation, should be used.

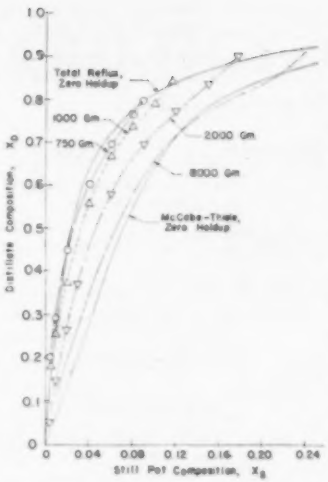

Fig. 21. Distillate composition vs. still pot composition.

Reflux ratio: 9/1
Charge composition (x_c): 0.254

Run No.	Charge g.	Legend
13	750	○
12	1000	△
21	2000	▽
30	8000	×

Initial distillate compositions at total reflux can be estimated for different charge sizes from a knowledge of column holdup. Once these are known, approximate low-holdup curves can be sketched, starting at the appropriate value, and rapidly approaching the McCabe-Thiele line.

A high-holdup experimental run can be made at an intermediate value of the reflux ratios under consideration. The resulting curve may be assumed to be the same as for the other reflux ratios at high holdup.

One experimental curve may be determined at an intermediate holdup for the lowest reflux ratio under consideration.

By the above means a set of curves such as those in Figure 22 may be estimated without undue difficulty. The zero-holdup (low charge) run (item 4) can be run quickly, and the value of average composition could serve as the approximate end-point for all the curves. The one run at an intermediate value of holdup would tell whether the curve for the lowest reflux ratio showed a maximum or not.

Once a set of curves such as Figure 22 is obtained, it would be easy to choose one or more sets of conditions which would give the proper separation. Economic considerations would then allow the best choice to be made.

This discussion has purposely dealt in general terms and avoided numerical quantities. It would be fairly safe to say that the high-holdup run should be made at about 50% holdup, and the intermediate-holdup run at about 25%. Reflux ratios considered should be approximately equal to the number of plates in the column.

Favorable and Unfavorable Factors of Holdup in Batch Distillation. It is suggested that the rather complicated and previously confusing effects of holdup arise because holdup actually affects the results in three distinct ways. Two of these are inertia effects and result in improved separation, i.e., in higher distillate compositions during the first part of a break. These two may be designated as (1) total reflux startup effect, and (2) the unsteady state inertia effect. The third effect is of the opposite nature in that it results in lower distillate compositions during the first part of a break. This is (3) the depletion effect.

The actual result in any particular distillation is determined by the relative magnitudes of these three factors. These may differ greatly for different mixtures, columns, and operating conditions and may change with fraction distilled during a single particular distillation. The situation is further complicated by the fact that (1) compositions during the early portion of a batch distillation have an effect on all subsequent compositions, and (2) the three holdup effects are not independent of one another.

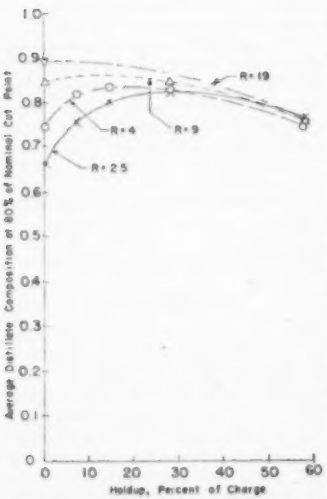

Fig. 22. Average distillate composition at 80% of nominal cut point vs. per cent of holdup (From Theoretical Calculations).

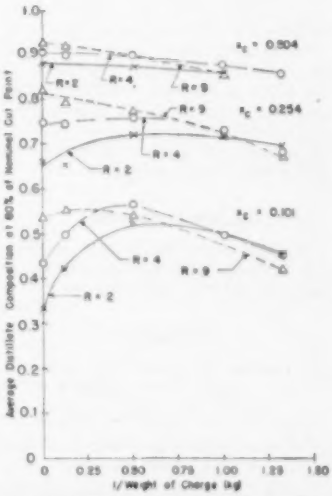

Fig. 23. Average distillate composition at 80% of nominal cut point vs. reciprocal of weight of charge (Experimental Values).

From the point of view of practical application, it seems that most large columns have so low a ratio of holdup to charge that none of the effects of holdup is large for ordinary binary distillation. From multicomponent distillation experiments (*17*) there is evidence that the important factor in the separation of a particular component is the ratio of holdup to the quantity of that particular component in the charge. When the quantity of a component is small, this ratio will be large and the effects of holdup likewise will be large, even in industrial columns with large still pots and small columns. The same may be said for distillation of binary mixtures with a small proportion of one component. Failure of plant equipment to produce separations as good as laboratory and pilot plant equipment has sometimes been due to relatively small holdup in the plant columns and large holdup (relative to charge) in the smaller scale equipment. It must be emphasized that marked effects of holdup are likely to be encountered in all kinds of small-scale distillation equipment in analysis and purification operations in the laboratory and pilot plant.

A few general statements may be made. Thus the total reflux startup effect would not be present if the startup were made with finite reflux. When total reflux startup is used, its effect is most pronounced at the origin of the distillation, and it therefore has a major effect on any breaks that occur early in the distillation, as in the distillation of mixtures with a small proportion of the most volatile component. Little is known of the unsteady state inertia effect except that it is governed by the operating line equation proposed by Colburn and Stearns (*2*). Indications are that it is small in most binary batch distillations, but may be of major importance in multicomponent batch distillation. The depletion effect results from concentration of the more volatile component in the column with a resultant decrease in still pot and head composition.

Acknowledgments

Grateful acknowledgment is made to the Research Corp. for financial assistance for the work described.

Notation

V = rate of vapor flow, mole/hr., from still or any plate

L = rate of liquid flow, mole/hr.

D = rate of product removal, or distillate, mole/hr.

H = (on figures) moles holdup as % of charge; (Equation (1)) moles liquid holdup on a plate

x = mole fraction of more volatile component in liquid phase

y = mole fraction of more volatile component in vapor phase

R = reflux ratio, L/D

SUBSCRIPTS:

n = number designating a particular plate in a column

D = distillate

s = still pot

c = charge

i = number designating short intervals of time since beginning of product removal

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Discussion

G. E. Barker (University of Michigan, Ann Arbor, Mich.): In applying your results to systems with lower constant relative volatilities, such as down to 1.1, would there still be an advantageous effect of holdup as well as the detrimental effect? In other words, would the inherently high reflux ratios required in such separations permit the increase in yields shown at low reflux ratios?

R. C. Johnson: With any binary mixture and any column, you could obtain experimentally sets of curves, such as have been found in this work, showing the effect of composition, reflux ratio, and holdup on the sharpness of separation. At least some of these curves should show a maximum sharpness at an intermediate value of holdup. It is entirely possible that you would always be working with such high reflux ratios in any practical case that all of your curves would slope downward, and thus, in such cases, holdup would have a detrimental effect.

Stanley E. Jaros (Standard Oil Development Co., Linden, N. J.): How did you vary the holdup and still keep all the other variables constant?

R. C. Johnson: Actually, in most columns, holdup is essentially constant. The important variable is the ratio of holdup to charge. Consequently, in most laboratory work, the per cent or fraction holdup is varied by varying the amount of charge. Effects of holdup may be shown graphically by plotting the dependent variable vs. the per cent holdup (which must be calculated) or, alternatively, vs. the reciprocal of the charge. It might be pointed out also that the actual holdup, expressed as a per cent of the material in the column at any time, would vary from the initial value to 100% if a distillation were carried out to completion; however, all correlations with holdup are made with respect to the initial holdup, i.e., the ratio of holdup to charge.

(*Presented at Atlanta (Ga.) Meeting.*)

CORRECTION

In "Pipe-line Design for Non-Newtonian Solutions and Suspensions" by G. E. Alves, D. F. Boucher, and R. L. Pigford, published in the August, 1952, issue of "C.E.P.," the last part of Equation (10), page 387, should read $B_1/\log_e(r_o/r_i)$, and the first entry in the Literature Cited, page 393, should be Alexander, J., "Thixotropy" in "Colloid Chemistry," **VI**, Reinhold Publishing Corp., New York (1946).

CHARACTERISTICS OF FLOW

IN FALLING LIQUID FILMS

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AN understanding of the mechanics of film flow is important in those cases of heat and mass transfer which involve two-phase flow. Flow in vertical condensers, film reactors, water tube boilers operating at high flow rates, and packed towers are a few practical examples of this flow configuration. Due to the absence of fundamental information concerning the hydrodynamics of the liquid film, mass- and heat-transfer analyses in industrial equipment have, in general, rested on empirical methods. The work here reported on films was undertaken in order to define more fully the liquid-film conditions so that the analysis of two-phase flow could be made on a rational basis and ultimately be extended to the transfer process.

It is of interest to examine the way in which the liquid conditions enter into the mass-transfer parameters. In a wetted wall column or packed column the partial pressure driving force is fixed by conditions in the gas and the equilibrium concentration of the solute in the solvent. The remaining factors affecting the transfer rate are the transfer coefficient and the interfacial transfer area. The transfer area depends on the wave motion at the gas-liquid interface and for liquid flow over a non-plane surface depends, in addition, on the liquid-film thickness. This area enters into the mass-transfer equations for cases of either gas or liquid-film controlling. The mass-transfer coefficient is independent of the liquid properties where gas-phase resistance is controlling. However, when the liquid resistance is significant, the coefficient is a function of liquid properties and internal turbulence. A lack of information which would permit a separation of these two factors of area and coefficient, has led to the use of a combined coefficient, ka, where a is the transfer area per unit volume of empty or packed tower. Since the transfer coefficient and a are independent functions of the liquid conditions, use of a combined coefficient makes a rational analysis difficult.

Weisman and Bonilla (*22*), investigating the variation of interfacial transfer area in a packed column for the gas-phase controlling case of water evaporation, demonstrated a dependence of this area on the square root of the liquid rate for mass transfer and proportion to the 0.3 power of liquid rate for heat transfer. They developed a similar functional relationship between the liquid rate and the H.T.U. which includes the interfacial area term. Cooper, Christl and Peery (*5*), absorbing carbon dioxide in water (liquid-resistance controlling), showed a strong effect of both liquid and gas rate on the H.T.U. values which Sherwood (*18*) attributed to the effect of these variables on the interfacial area. Pigford (*16*) has also suggested that the transfer rates across fluid-fluid interfaces are higher than across fluid-solid boundaries due to the presence of interfacial waves. Thus for both liquid- and gas-film controlling, a knowledge of the liquid-film characteristics is important to an understanding of the transfer process.

Literature Background

Film Thickness. Nusselt (*15*), attempting to analyze the phenomenon of heat transfer to falling vertical films presented one of the earliest useful analyses of film thickness. His equations, derivable from force balances on an element in the liquid film, were developed with the assumptions of viscous flow where no shear or wave motion existed at the liquid surface. The equation for mean film thickness is

$$\Gamma = \frac{\rho_L^2 g m^3}{3\mu_L} \qquad (1)$$

Fallah, Hunter and Nash (*8*) and Cooper, Drew and McAdams (*6*) have redeveloped these equations retaining the assumptions of viscous flow and a smooth interface but introduced the concept of an interfacial shear. Resulting equations contain terms involving the interfacial shear or interfacial velocity but since these terms are, in general, unknown the equations cannot be solved for the general case.

Early experimental data on the thickness of liquid films were obtained by Hopf (*11*), Chwang (*4*) and Schoklitsch (*17*). For low rates of flow (Reynolds numbers below 1000) and where the channel was mounted nearly horizontal so that no wave motion existed, good agreement with Equation (1) was obtained. Kirkbride (*12*) attempted to measure the thickness of films flowing on the outside of a vertical cylinder using a micrometer technique but the data obtained did not agree well with the Nusselt equation above a Reynolds number of eight when waves appeared on the liquid surface. Use of this micrometer technique yielded data which represented the maximum film thickness rather than the mean.

Film thickness on vertical surfaces has also been measured by stopping the flow, weighing the drainage and adding to this quantity the weight of liquid adhering to the wall as determined by wiping with tared toweling. Claassen (*3*), Warden (*21*) and Fallah, Hunter and Nash (*8*) used techniques based on this principle of measurement and demonstrated that at a low Reynolds number (below 1000) the Nusselt equation predicted the experimental mean film thickness even when waves were present at the gas-liquid boundary.

No theory has appeared in the literature concerning film thickness for the important practical case of a turbulent film where an interfacial shear exists. Carpenter and Colburn (*2*) discussed the effect of vapor velocity on the condensation heat-transfer coefficient in a vertical film condenser. By assuming that the main resistance to heat transfer is in the laminar sublayer, and that in the presence of interfacial shear the velocity gradient in the liquid film is linear, these investigators developed an expression for the heat-transfer coefficient which is

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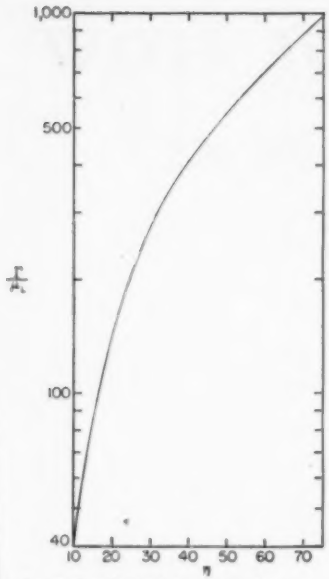


Fig. 1. Graphical solution of Equation (9).

fairly well supported by their data for various condensing liquids. With the exception of a few experiments by Fallah et al (*8*) where a moving liquid core immiscible with the wall liquid was used, no direct experimental data for liquid-film thickness have been reported for liquid films with interfacial shear.

Wave Motion. Early observers noted that waves appeared on the surface of a vertical liquid film at extremely low flow rates where the classical Reynolds dye experiment indicated that the overall flow was viscous. Grimley (*10*) has stated that wave motion in the film can be expected at a Reynolds number of 25 and suggests that this motion is quite regular in nature from this low Reynolds number to an upper limit of about 1000. A transition region appears as the flow rate is increased after which a more agitated type of wave is generated which is quite random in nature and suggests turbulent motion. Grimley also presents several photographs of wave motion on the surface of the liquid which were obatined by the electric spark technique. There have been no published quantitative data on the wave profile for falling liquid films.

Development of Equations

A simplified relation between film thickness and pressure drop is now developed for turbulent film flow with interfacial shear (two-phase flow) acting in the direction of the liquid flow.

Von Karman (*20*) has suggested the existence of a universal velocity distribution equation for turbulent flow in terms of two parameters, u^+ and y^+ which are defined as:

$$u^+ = \frac{u}{u^*} \qquad (2)$$

$$y^+ = \frac{u^* \rho_L y}{\mu_L} \qquad (3)$$

Data of Nikuradse (*14*) verified this hypothesis, made possible the evaluation of the experimental constants for flow in circular pipes and demonstrated the existence of a buffer region between the laminar sublayer and the main turbulent stream. Resulting equations and the limits of application suggested by the data of Nikuradse are:

$$u^+ = y^+ \qquad 0 < y^+ < 5 \qquad (4)$$

$$u^+ = -3.05 + 5.0 \ln y^+ \qquad 5 < y^+ < 30 \qquad (5)$$

$$u^+ = 5.5 + 2.5 \ln y^+ \qquad 30 < y^+ < \eta \qquad (6)$$

By assuming that these equations which were developed for full pipe flow apply to the liquid phase in two-phase film flow, it is possible to develop a relationship between film thickness and pressure drop over the viscous to turbulent flow range. Although such an assumption is probably not satisfied under certain conditions discussed below, it is consistent with the reasonable physical picture that the liquid in the film below the interface is unable to distinguish between an adjacent shear which has been transmitted ultimately from a liquid or gas source moving as a center core. Picturing the gas core replaced by a liquid stream moving with such a velocity distribution that the interfacial shear is unchanged, it appears reasonable to apply Equations (4)-(6) to the liquid film flowing along the wall as long as the remaining conditions under which these equations were developed are not violated. In pipes flowing full, velocity gradients in the turbulent core are not large, and therefore these equations, the constants for which were evaluated from full pipe experiments, are incapable of describing a situation in the falling film where large gradients exist. This would be the case for large interfacial shear. However, since the shear force at a point is the product of the eddy viscosity and the velocity gradient and since the eddy viscosity can be expected to be very large near the interface, it is reasonable to expect that even for appreciable interfacial shear the gradient must be small and the equations developed for full pipe flow should describe the film flow reasonably well.

Additional confidence in the use of these full pipe equations for a different flow geometry results from the fact that Gazely (*9*) recalculated the data of van der Hegge Zijnen (*19*) for the flow of air over a flat plate to the universal basis and demonstrated that the constants and form of the equation for the velocity distribution in the turbulent boundary layer were almost identical to Equation (6) for full pipe flow.

The weight rate of liquid flow per unit breadth can be defined as follows in terms of the universal parameters.

$$\Gamma = \mu_L \int_0^\eta u^+ dy^+ \qquad (7)$$

where η is the magnitude of y^+ at the interface. Equation (7) cannot be solved in one integral since u^+ is a different function of the distance parameter, y^+, for each of the three regions of flow. However, this integration can be accomplished by dividing the integral of Equation (7) into three parts delineated by the boundary conditions for the three regions of flow and substituting for each u^+ the proper defining equation.

$$\frac{\Gamma}{\mu_L} = \int_0^5 y^+ dy^+ + \int_5^{30} (-3.05 + 5.0 \ln y^+) dy^+ + \int_{30}^{\eta} (5.5 + 2.5 \ln y^+) dy^+ \qquad (8)$$

Integrating and collecting terms gives

$$\frac{\Gamma}{\mu_L} + 64 = 3.0\eta + 2.5\eta \ln \eta \qquad (9)$$

For any flow rate Γ can be calculated and η evaluated from this equation. In order to eliminate trial-and-error solution Figure 1 has been prepared. Note that Γ/μ_L is one fourth the Reynolds modulus for film flow. By definition η is seen to be

$$\eta = \frac{u^* \rho_L m}{\mu_L} \qquad (10)$$

The friction velocity is related to the wall shear by

$$u^* = \sqrt{\frac{\tau_{wg}}{\rho_L}} \qquad (11)$$

In order to complete the analysis it is now necessary to derive the relation between pressure drop and wall shear from a force balance. The configuration of a vertical cylindrical pipe is presented here but this can be modified readily for a different geometry of flow. For steady-state-flow the vector sum of the forces acting on any element of fluid must equate to zero. Thus the weight of liquid and gas in a length, dL, measured along the tube axis, plus the pressure drop acting on the cross-sectional area

of the pipe must exactly balance the shear force acting on the lateral area of the pipe within the dL length. Substituting for the weight of liquid and gas in terms of their respective volumes and density and using the definition of the differential gives the relation,

$$\tau_o = \left[\rho_G - \frac{dP}{dL}\right]\frac{r}{2} - \frac{2rm - m^2}{2r}[\rho_G - \rho_L] \qquad (12a)$$

When the film thickness, m, is much smaller than the pipe radius and when the gas density can be considered negligible compared to the density of the liquid then Equation (12a) reduces to the simpler form of (12b).

$$\tau_o = \left[\rho_G - \frac{dP}{dL}\right]\frac{r}{2} + m\rho_L \qquad (12b)$$

The wall shear can also be expressed in terms of the gravitational force on the film and the interfacial shear,

$$\tau_o = \tau_i + m\rho_L \qquad (12c)$$

from which it can be seen that the first pressure-drop term of Equation (12b) is the interfacial shear.

$$\left[\rho_G - \frac{dP}{dL}\right]$$

is the pressure drop due to friction.

With Equations (9) and (12) and with the definition of u^+ it is possible to calculate the liquid film thickness. For any liquid Reynolds number η is determined from Equation (9) or Figure 1. A liquid-film thickness is then assumed and the wall shear is calculated from Equation (12b) and substituted into the definition of η. The correct film thickness has been assumed when the value of η thus calculated agrees with that determined from Equation (9). Because of the nature of these equations this trial-and-error technique converges rapidly and more than three trials are seldom necessary to obtain reproducibility to 0.001 in. of film thickness. One set of calculations can be completed in five minutes with practice.

These general equations can now be simplified for the case of no pressure gradient (film flow in a tube or along a flat plate without forced flow of a gas phase). Under these conditions the first term in the shear equation vanishes and the wall shear becomes

$$\tau_o = m\rho_L \qquad (13)$$

Substituting this equation into the definition of η gives

$$\eta = \frac{\rho_L g^{1/3} m^{2/3}}{\mu_L} \qquad (14)$$

Now for any liquid flow rate η is calculated from the general equation as previously but the film thickness can be determined directly from Equation (14) without the need for a trial-and-error procedure. These equations apply for flow over a flat plate as well as in a tube when the thickness of the film is small over the curved surface.

Because these equations were derived from a summation of the flow rate per unit periphery in each of the three regions of flow (see Eq. (8)) they describe the film thickness over the entire flow range and are not restricted in use as are the previous equations for viscous flow. At low rates where the film thickness is small this equation predicts the film thickness for a laminar film. At successively higher liquid rates additional increments of film thickness are added and the regions of "buffer" and turbulent flow are superimposed on the laminar sublayer. Since the limits of each of these flow regions are defined by the experimental data of Nikuradse in terms of the universal parameters, it is possible to calculate the Reynolds number at which transition between laminar and turbulent flow occurs by use of the integrated equations developed here. On the basis of the experimental data which follow for flow without surface shear, the laminar and buffer regions have been grouped into an effective laminar layer and it is proposed that when the thickness of the film is such that the flow can be described by the laminar and buffer equations then the theoretical Nusselt equation will be satisfied. The universal distance parameter at the outer boundary of the buffer layer is 30. From Equation (9) or Figure 1 it is seen that this corresponds to a Γ/μ_L of 1270 or a Reynolds number of 1080. This means that the flow is laminar when the film thickness, as calculated on the universal basis (Equation (3)), is not larger than 30. As the flow rate is increased the film thickness increases and η exceeds 30. Then part of the film is in turbulent motion and the equations developed for viscous flow alone will not be satisfied. Experimental data will be presented to verify this predicted transition value and to demonstrate that the film which contains even a small segment in turbulent motion no longer satisfies the viscous-flow equations.

Experimental Equipment

Flow Plate. In order to create a flowing film with a minimum of external disturbance a vertical channel of high aspect ratio was constructed of wide, smoothly polished stainless steel with brass angle irons bolted along each edge. This plate was 24 in. wide with an over-all length of 8 ft. The top 5½ in. were bent along a sharp edge to create a plane 160 degrees to the polished face and liquid was introduced by free fall from a weir box onto this inclined plane. The remaining 7 ft. 6½ in. were mounted on 1-in. plywood which was supported on floor-to-ceiling posts. The plate was aligned with the vertical to within 0.1 in. over the entire length with a surveyor's transit. Liquid was pumped by means of a turbine-type pump through a rotameter and to the weir box where the flow was distributed by means of baffles and screens before dropping to the inclined section of the plate. After flowing down the plate the liquid entered a collection trough from which it was recirculated. Lengths of flexible tubing installed in the lines between the pump and weir box and collection trough minimized the transmission of vibration from the pump to the flow plate. All film thickness measurements were taken 2 ft. from the lower end of the plate where it was found that steady-state flow conditions existed with respect to the mean flow. A schematic diagram of this apparatus appears in Figure 2.

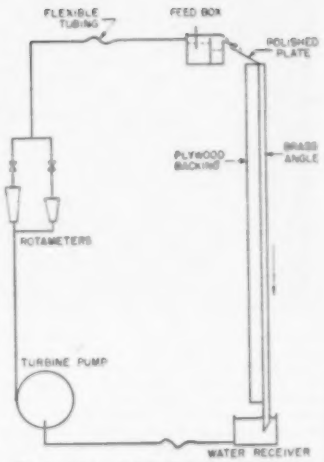


Fig. 2. Schematic flow diagram of flat-plate apparatus.

Capacitance Apparatus for Measurement of Film Thickness and Wave Profile. Previous methods of film-thickness measurement have been of limited use because of two major disadvantages. Kirkbride (*12*) has pointed out that methods based on micrometer measurement to the liquid surface at a point have been in error due to the presence of wave motion which yields data in terms of the maximum film thickness instead of a reasonable mean. Methods based on drainage of holdup make it impossible to obtain point conditions and the data represent an average which includes those regions of unsteady-state flow where the liquid is accelerating as well as regions where a constant film thickness exists. Although it is of interest to examine these unsteady-state regions, data in terms of an over-all average film thickness is not readily subject to a theoretical analysis.

In order to permit the measurement of average film thickness over a small area without the need for contact with the surface of the liquid, a capacitance method has been examined. Figure 3 will serve to clarify the principles on which this method is based. Consider two parallel, conducting plates, *A-A* and *B-B* mounted vertically. Plate *A-A*, the flow plate, is fixed in position, while *B-B*, the probe, is arranged so that it can be moved to vary the normal distance while maintaining the parallelism. The capacitance of this condenser, which is measured by a sensitive capacitometer (described later), is directly proportional to the dielectric constant of the material be-

Fig. 3. Diagram demonstrating capacitance method for measuring film thickness.

tween the plates and the area of the plates, and inversely proportional to the normal distance. A calibration plot of air gap vs. capacitance can be prepared by varying and accurately measuring the distance between the plates and for each position determining the capacitance from the capacitometer. Now set the probe (*B-B*) a measured distance, m_o, from the flow plate, *A-A*, and cause water to flow over the latter plate. For this simple illustration, assume a smooth interface represented by *C-C*. Because of the high conductivity of tap water the capacitance of this condenser will now be essentially the same as if the two dry plates were separated by the distance, n_o. By reading the capacitometer indication when water is flowing and referring to the calibration curve the distance, n_o, can be determined. Since the distance, m_o, was originally fixed and known, the film thickness, m_n, can be evaluated by difference. The air gap, when water is flowing, can be made quite small by positioning *B-B* as close as is necessary to *A-A* before the water flow is started and thus the errors involved in taking the difference between two large numbers can be avoided.

The assumption inherent in the use of this method, that the surface of the water acts as a conducting plate, has been verified by measurements of the depth of stationary pools of water in horizontal troughs where an accurate value of liquid depth can be obtained from volumetric measurements. It was found that the capacitance-determined liquid depth agreed to within 0.001 in. with the depth calculated from a knowledge of the volume of water and the dimensions of the trough. Although the dielectric properties of water can be neglected, when determining the thickness of nonconducting films, such as oil, the capacitance contribution of the liquid film must be accounted for in the equations.

As discussed previously, the surface of the liquid is covered with waves at all but extremely low flow rates and, as a result, the assumption of a smooth interface in Figure 3 is not valid. However, because of the nature of the capacitometer described, when waves appear on the liquid surface and when the probe size is small, the capacitometer indicates the root mean square air gap and film thickness which, for a small degree of wave motion does not differ appreciably from the integrated mean film thickness. For a wave profile with large waves of high frequency the r.m.s. film thickness may differ considerably from the mean with the r.m.s. thickness always the greater value.

If the probe size is reduced to a dimension smaller than that of a wave length it is possible to extend this capacitance technique to the evaluation of wave profiles. With a small probe and using a capacitometer capable of measuring and indicating a continuously varying function of capacitance on an oscilloscope tube, permanent records of wave height as a function of time were obtained by photographing the deflection of the electron beam with a drum camera. With this small probe the capacitance depends on the portion of the wave which is below the probe at any instant. When the peak of the wave moves past the stationary probe the capacitance is a maximum and decreases as the wave height decreases and the air gap increases. For these experiments the probe was less than ⅛ in. long in the direction of flow and approximately $^3/_{16}$ in. wide. This probe was set into a nonconducting Plexiglass frame which in turn was mounted on the shaft of a depth gage calibrated to within 0.001 in. The frame of this gage was fixed to a stationary post in front of the flow plate and the air-gap distance was varied by means of a screw travel arrangement.

Because the small area of this probe results in small capacitances between the probe and the flow plate (or the liquid surface) it was necessary to use an extremely sensitive capacitometer to measure the film thickness and the variations due to wave motion. The apparatus constructed for this purpose is schematically illustrated in Figure 4. Based on a frequency modulation method of detection, this equipment consists of a 6AU6 oscillator circuit, a discriminator network, a two-stage amplifier, power supplies and an oscilloscope tube all mounted on one chassis. A photograph of this equipment mounted in position to measure film thickness or wave profile on the flow plate is shown in Figure 5. A typical calibration curve of air gap or film thickness as a function of the instrument microammeter reading (which is a function of capacitance) appears in Figure 6 from which it can be seen that over the range of distances used in this work the relation between capacitance and air gap is approximately linear.

Experimental Data

Film Thickness. The experimental determination of the thickness of water films was carried out using the equipment just described over a range of water rates which include both viscous- and turbulent-flow states. Typical data for two runs appear in Table 1. Data are plotted in Figure 7 where a comparison is made with the prediction of the Nusselt equation as well as with the new equations just developed. Complete data and a more extensive discussion of the technique may be found in (7). The significant conclusions which can be drawn from this graph follow.

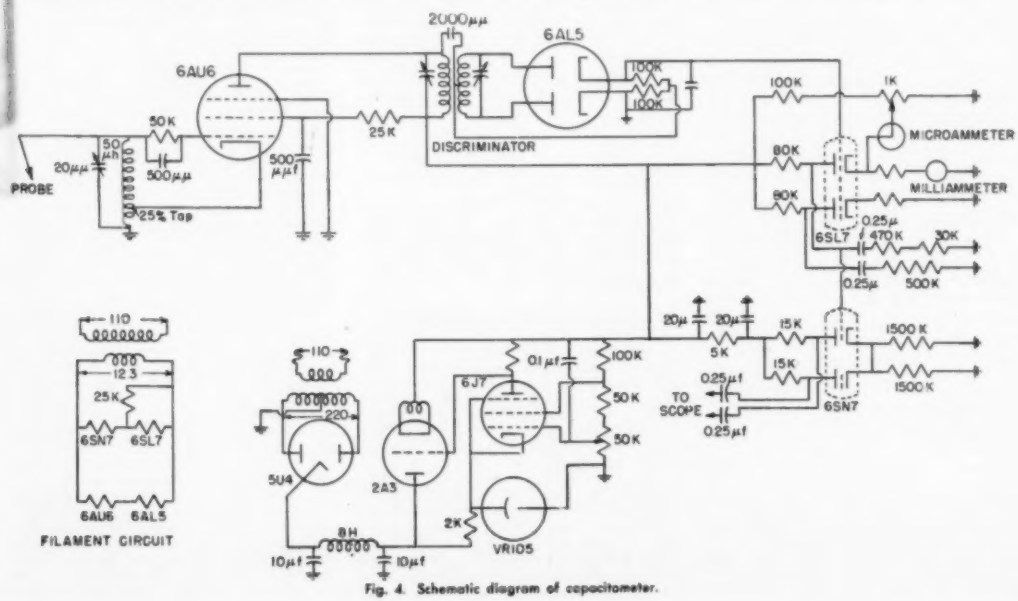


Fig. 4. Schematic diagram of capacitometer.

1. The new equations (dotted line) reduce to exact agreement with the Nusselt equation (solid line) at a Reynolds number of approximately 1000 below which point one line describes both equations. Thus these new equations, developed from a universal velocity distribution principle, duplicate the Nusselt values in the range in which the latter are known to be valid.

2. At Reynolds numbers below 1000 the experimental film thicknesses, as determined by the capacitance technique, agree closely with the predicted values. In this low Reynolds number region the experimental data fall about the theoretical line with a maximum deviation of 5% indicating an instrument accuracy better than 0.001 in. The experimental data begin to diverge from Nusselt theory for viscous flow at a Reynolds number of 1000 which is quite close to the theoretically predicted value of 1080. These data verify the observations of other investigators that in spite of wave motion the Nusselt equation predicts accurate values of mean film thickness in the viscous region.

3. In the turbulent region, experimental data tend to substantiate the new film thickness equations represented by the dotted line. It is in this region that the new theory deviates from the Nusselt predictions. Experimental points are uniformly higher than the theoretical line. High values are obtained because wave motion is sufficiently large to cause significant differences between the mean film thickness as given by the equations and the r.m.s. film thickness obtained from the capacitometer. In fact, as the Reynolds number increases, with an accompanying increase in wave motion, the spread between the theoretical mean and the experimental r.m.s. film thickness increases. The maximum deviation is approximately 10% at the highest flow rate studied. In order to correct the r.m.s. thickness to a mean value it is necessary to have quantitative wave-profile data. Wave-profile studies will be discussed below. From these studies it was found that at a Reynolds number of 3000 the integrated mean film thickness was smaller than the r.m.s. film thickness by 0.0015 in. If this correction is applied to the experimental point at a Reynolds number of 3000 it is seen that the resulting value falls quite close to the theoretical line. Equations (9) and (14) then predict the thickness of liquid films when the film is in either viscous or turbulent flow for the case where no interfacial shear exists. However, recalling that these equations were obtained by a simple reduction in the general equations accounting for interfacial shear, the more general equations are tentatively verified. Direct experimental verification for cases with shear will be necessary in order to test the applicability of the von Karman equations to cases where significantly large velocity gradients exist at the interface.

Wave-Motion Studies. Considerable discussion of wave motion in stationary pools of liquid can be found in Lamb (*13*). However, this work cannot be applied to the case of thin films in motion or to the vertical wave profile. It has only been in recent years that modifications to the horizontal wave-motion theory have permitted extensions to cases of finite liquid depth. However, when the wave height approaches in magnitude the thickness of the liquid film, as in the case of these thin film studies, the mathematics appears, at this time, excessively complex. The wave-motion studies described in this paper were directed along experimental lines.

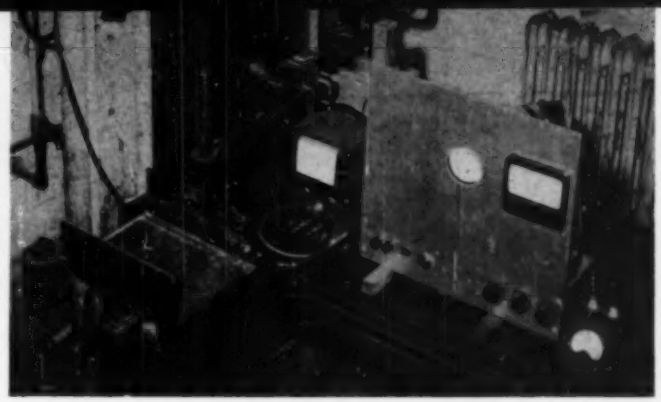


Fig. 5. Flow plate and capacitometer.

In order to obtain some over-all indication of the nature of the wave motion, high-speed flash photographs of flow over the vertical plate were taken at various Reynolds numbers. Four photographs of the liquid surface at increasing liquid rates are presented in Figures 8-11. In each photograph the band of light represents back reflection from the highly polished flow plate. Reynolds numbers range from 756 to 1565, thus including both viscous and turbulent flow. The complexity of the flow pattern is apparent from these pictures. Even at the lowest flow rates large wave fronts exist which are surrounded by fine capillary waves having the same general contour as the primary wave. As the water rate increases, the number of waves in a given area increases, the wave spacing is smaller and cases where two waves join appear. The scale for all of these pictures is identical. These photographs demonstrate that wave motion on the liquid surface causes the interfacial area to differ considerably from that calculated from the area of the confining channel; and show also that this area changes because of increased wave motion as the flow rate increases. From this information it is apparent that the assumption of a constant interfacial area, inherent in the use of a combined coefficient, k_0, may be in considerable error.

A quantitative measure of the wave profile was obtained from the oscilloscope deflections photographed with a drum camera while water was flowing on the plate. Several such strip films are reproduced in Figures 12*a-d*. These films are essentially plots of wave amplitude against time.

TABLE 1.—FLOW OF WATER OVER A VERTICAL PLATE

Run 3A

Liquid T.: 77° F.

Liquid Flow Rate lb./hr.	Reynolds Number	Film Thickness * in.
1266	1171	0.017
1524	1410	0.018
1748	1652	0.021
1254	1161	0.017
918	850	0.014
1626	1505	0.019
852	789	0.014
522	483	0.013
1986	1840	0.022
2508	2325	0.025
2988	2770	0.028

* Film thickness data obtained with capacitometer.

Characteristics of this capacitometer are such that the oscilloscope indicates the a.c. variation of capacitance due to wave motion around the r.m.s. level of capacitance due to the film thickness. Vertical deflection on the scope face is linear with capacitance by instrument design and since capacitance has been shown to be linearly related to air-gap distance (Fig. 6) then the amount of deflection of the electron beam is related linearly to the air-gap distance. That is, a given deflection represents a certain air-gap distance and wave height above the r.m.s. level. Twice this deflection would represent one-half the previous air gap and therefore twice the previous wave height above the r.m.s. film thickness. The nondeflecting position of the beam represents the r.m.s. film thickness. This is indicated by the lower white line along the length of the film. The upper white line represents a 1-in. deflection of the beam and indicates a wave height of 0.014 in. above the r.m.s. film thickness for these pictures. Any intermediate position on the trace can be related

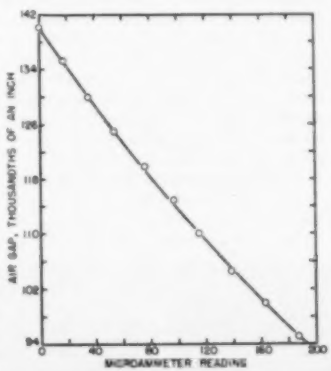


Fig. 6. Measurements of film thickness for flow over a flat plate. Capacitometer calibration curve.

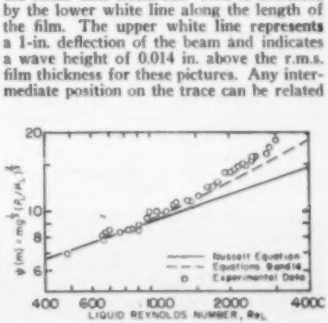


Fig. 7. Variation of ψ (M) with liquid Reynolds number. Comparison of experimental data with theory.

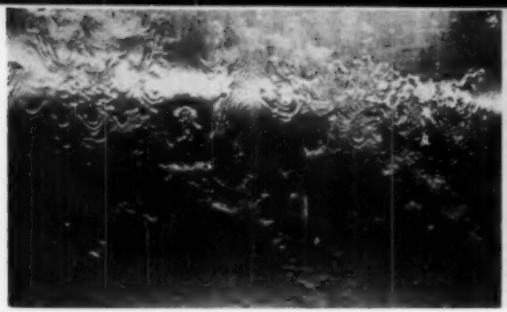


Fig. 8. Wave motion on falling film. Reynolds number = 756.

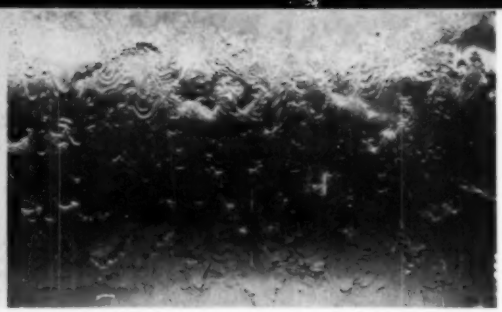


Fig. 9. Wave motion on falling film. Reynolds number = 916.

to wave height above the r.m.s. value by linear interpolation or, for thicknesses less than r.m.s., by extrapolation. For example, consider Figure 12*b* where the lower horizontal line represents an r.m.s. film thickness of 0.017 in. At any point on the wave profile which is positioned on the middle white line the wave height is ½(0.014) in. above the r.m.s. film thickness or represents a wave height of 0.024 in. On these photographs 1 in. of film represents 0.134 sec.

By integrating the profile to obtain the area under the curve and dividing by the time interval over which the integration was performed the average deviation between the mean and r.m.s. film thickness can be determined. Because of the transient nature of the waves this must be done over a long period of time in order to get a reliable value. By integrating 7 min. of strip film taken when liquid was flowing at a Reynolds number of 3000, the correction to the r.m.s. thickness to give the mean was found to be 0.0015 in.

At low rates of flow (Fig. 12*a*) the waves are widely spaced with long troughs between each large wave and with capillaries following the peaks. The flow appears quite regular in nature. As the flow rate is increased this simple motion is replaced by flow with a greater frequency of large waves with the individual waves no longer simple in form. The wave front appears steep with the trail sloping and followed by smaller waves which are no longer of capillary size. The wave troughs are not as long but are considerably deeper and more sinusoidal than for lower rates of flow. At the highest rates observed here the flow is extremely complex and random in nature. Double and large secondary waves appear as the wave frequency becomes quite large.

Because of the random nature of this type of wave motion it is subject to analysis by statistical methods. For this purpose strip films over a long period of time are necessary and the time axis must be related to the travel along the flow plate. This can be done by using the point velocity at the cross section of the wave under consideration. Because this study was directed mainly toward an evaluation of apparatus for determining wave profiles, extensive analyses of this type were not made but a sufficient preliminary investigation into the method was completed to indicate its suitability. In using the statistical approach the analyst must keep in mind the fact that these wave profiles are obtained with a probe of finite area and are therefore not point profiles but averages over an area somewhat greater than that of the probe.

These limited wave-profile studies indicate that the capacitance technique is a useful tool for the study of gas liquid interfacial motion. With properly designed probes it is possible to extend this study to a system such as a wetted-wall tower where a gas moves simultaneously with the liquid stream and creates an interfacial shear. In this manner the effect of interfacial shear on wave motion can be determined. The authors suggest that with this method of obtaining profiles future investigators may be able to apply the principles of statistical analysis to the problem of wave motion in two-phase flow and derive those data concerning available surface which will assist in clarifying the mass-transfer problem.

Summary

1. New equations are developed using the von Karman velocity distribution theory which relate liquid-film thickness in cocurrent, gas-liquid flow to the flow rates, physical properties of the fluids and to the energy loss. For the case of no gas flowing, the equations reduce to give the film thickness as a function of flow rate and physical properties over the complete viscous to turbulent flow range. It is shown that the transition from laminar to turbulent film flow occurs at a Reynolds number of 1080.

2. Equipment is described for the measurement of liquid film thickness and wave profile based on a capacitance technique and this equipment is shown to be capable of measuring film thicknesses to an accuracy of 0.001 in.

3. Measurements of the thickness of water films flowing down a vertical plate by the capacitance technique substantiate the theoretical equations developed for this case to within 0.001 in. The experimental data also demonstrate that the transition Reynolds number is approximately 1000.

4. High-speed flash photographs of the liquid surface and wave profiles determined with the capacitometer are presented which describe the nature of the wave motion for flow over a vertical plate.

Acknowledgment

The authors wish to acknowledge the assistance of D. Clements, of the electrical engineering department, University of Delaware, who constructed the capacitometer described in these studies. The financial assistance of the Shell Oil Co., through the Shell Fellowship, is gratefully acknowledged. This work is a part of a research program on two-phase flow which was initiated by a grant from the Research Corp.

Notation

a = interfacial transfer area, sq. ft./cu.ft. of packed or empty tower

g = gravitation conversion constant, 32.2 (lb.)(ft.)/(sec)^2(lb. force)

k = mass-transfer coefficient, lb./(hr.)(sq.ft.)

m = film thickness, ft.

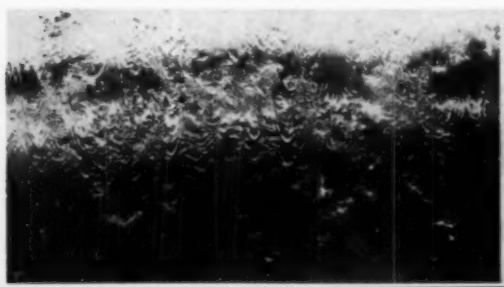
$\frac{dP}{dL}$ = pressure gradient, lb. force/(sq.ft.)(ft.)

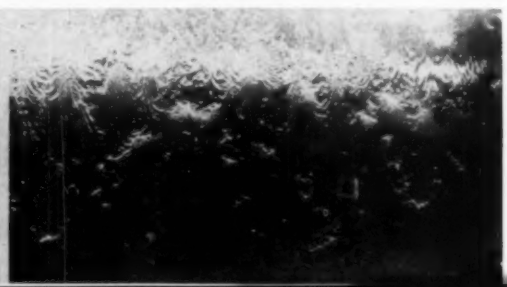
r = pipe radius, ft.

u^* = friction velocity defined by Eq. (11), ft./sec.

Fig. 10. Wave motion on falling film. Reynolds number = 1300.

Fig. 11. Wave motion on falling film. Reynolds number = 1565.





u^+ = universal velocity parameter defined by Eq. (2), dimensionless

y = distance from the wall into the film, ft.

y^+ = universal distance parameter defined by Eq. (3), dimensionless

GREEK LETTERS:

Γ = liquid flow rate/unit channel periphery, lb./(hr.)(ft.)

μ_L = liquid viscosity, lb./(ft.)(hr.)

η = magnitude of the universal distance parameter at the liquid surface

ρ_G = gas density, lb./cu.ft.

ρ_L = liquid density, lb./cu.ft.

τ_i = shear stress at the interface, lb. force/sq.ft.

τ_o = shear stress at the wall, lb. force/sq.ft.

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Discussion

D. I. Saletan (Shell Chemical Corp.), Martinez, Calif.: You make the point of the desirability of separating the combined coefficient termed ka. Now I can see justification for this only if k and a are dependent variables of different independent variables. But are they not in this case determined by the same things, velocity of air stream and velocity of the flowing film?

A. E. Dukler: The major reason for separating the coefficient, k, from the area factor, a, is that while k depends on the degree of turbulence in the liquid film, the interfacial area varies not only with the degree of wave motion but also with the particular apparatus used for the transfer process. Thus combined coefficients obtained on one unit, say packed towers, are not applicable to another type of unit, say a wetted-wall tower or spray column. On the other hand, under the same conditions of turbulence, the analogies tell us that the coefficient based on a unit area may be translated from column to column if similar flow conditions exist. This can never be done in a fundamental manner with the combined coefficient, ka. For this same reason any study which attempts to relate the transfer coefficient to the flow must deal with k, not ka.

D. I. Saletan: Is there any one independent variable that will change one of them without changing the other?

A. E. Dukler: The transfer area depends on the wave profile in this wetted-wall column while k varies with the turbulence in the liquid film when we are talking about a liquid-film coefficient. Both are functions of the flow variables but, as pointed out in the paper, are not the same function of these variables. The exact relationships are not known but we do know that wave motion can be initiated at liquid rates which indicate that the film is in laminar motion. Considerable changes in the liquid velocity can be made which result in changes in the wave profile and interfacial area without changing the flow to the turbulent type. In this case then we have changed an important variable, the liquid velocity, and have changed the interfacial area while the transfer still takes place by a molecular transport mechanism.

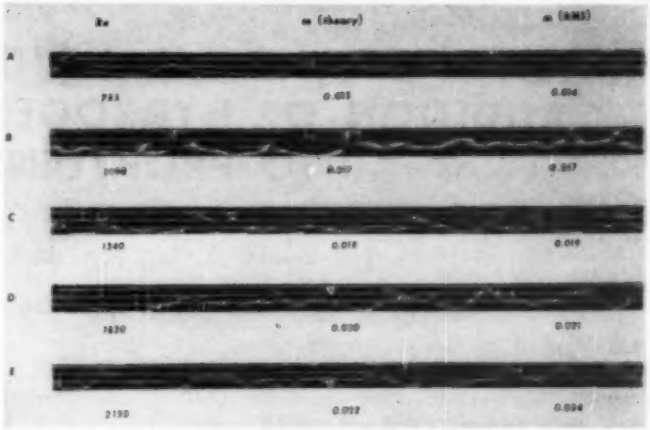

Fig. 12. Drum photographs of oscilloscope tube. Water waves moving past probe. Total strip length represents 1.11 sec.

Distance between any two horizontal lines represents 0.007 in. of wave height.

H. D. Evans (Shell Development Co., Emeryville, Calif.): I gather that polished steel plates were used for your work. This may be an unreal situation for some kinds of industrial application. How would film thickness and film shape differ for other plate surfaces and other roughnesses?

A. E. Duklar: Well, it would depend upon the degree of roughness, of course. I think if the roughness were small enough to lie within the laminar sublayer it would have no effect at all. If you had protuberances which extended beyond the thickness of the laminar sublayer which would be smaller if you had a higher interfacial shear, or larger depending upon the direction of the gas flow. We have done some work on the interpretation of these waves as presenting roughness to a gas stream moving by, and that too will be the subject of a later paper.

H. D. Evans: Would you say generally that polishing the plates would have no effect on the characteristics you have been talking about?

A. E. Duklar: Within limits,-within the laminar sublayer.

(Presented at A.I.Ch.E. Forty-fourth Annual Meeting, Atlantic City, N. J.)

KINETICS OF THE CATALYTIC VAPOR-PHASE ADDITION OF HYDROGEN CHLORIDE TO PROPYLENE

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University of Cincinnati, Cincinnati, Ohio

A kinetic study was made of the vapor-phase addition of hydrogen chloride to propylene using alumina as a catalyst. Preliminary investigation indicated that isopropyl chloride is the only product formed at temperatures of 80° C. or less when this catalyst is used. The catalyst activity was found to decrease with time, possibly due to the deposition of propylene polymer products on the catalyst surface.

The results of this study indicate that the reaction is not controlled by either the adsorption of hydrogen chloride or the adsorption of propylene. The reaction may be controlled by the desorption of isopropyl chloride or by the surface reaction. The kinetic data are correlated by rate equations derived by two different methods based on the surface reaction as the controlling mechanism.

THE purpose of this investigation was to determine the kinetic behavior of the reaction between hydrogen chloride and propylene over activated alumina to produce isopropyl chloride. It is hoped that this study will initiate a series of similar research on the addition of hydrogen chloride to other members of the olefin–1-hydrocarbon series. The ultimate objective is the development of some interrelationship between the kinetic behavior of members of a homologous series toward one particular reaction.

The previous literature (*1* to *8*, *11* to *14*), primarily patents, deals with the technological phases of the reaction and does not provide the fundamental kinetic data. Activated alumina is indicated to be an active catalyst and to give a reaction with no by-products provided the reaction temperature is below 100° C. Both of these characteristics were verified in this work.

Table 2 (Experimental Data) and Table 3 (Conversion at Process Time 0 Hours) are on file (Document 3695) with the American Documentation Institute, 1719 N St., N.W., Washington, D. C. Obtainable by remitting $1.00 for microfilm and $1.00 for photocopies.

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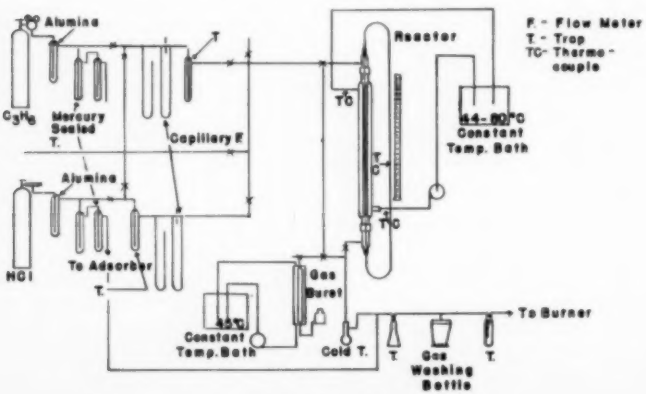

Fig. 1. Layout of experimental equipment.

Experimental Equipment

The general layout of the experimental equipment is shown in Figure 1. The reactor consisted of a standard 50-cm. condenser fitted with 24/40 glass joints. A 2-mm.-O.D. glass thermowell was centered in the 10-mm.-I.D. reactor and sealed to the glass joints with sealing wax. Bed temperatures were measured with a 26-gage chromel-alumel thermocouple which was capable of axial travel and precise positioning within the reactor. Reaction temperatures were controlled by water circulating from a constant-temperature bath through the jacket at a rate of 0.22 gal./min. Chromel-alumel thermocouples placed in the water line before and after the reactor measured inlet and exit water temperatures.

The individual streams of hydrogen chloride and propylene were purified by passing through cold activated alumina. They were metered and then mixed in the preheating section of the reactor. No reaction occurred during mixing and preheating. Any liquid product was collected in a cold trap; hydrogen chloride was removed by absorption in water, and then the product stream was destroyed by burning. Samples of the feed and product gases were bled into a 100-cu.cm. gas buret maintained at 45° C. to prevent any condensation of isopropyl chloride. After the volume of sample was measured, the gas was transferred to an absorption tube constructed of 15-mm. glass tubing. The absorption tube had a capacity of approximately 95 cu.cm. and was fitted with one stopcock at one end and two stopcocks at the other end to facilitate draining and washing. A 300-cu.cm. reservoir bottle was connected to the absorption tube by Tygon tubing.

Materials

Propylene. The propylene was C.P. grade and had a listed purity of 99% with the principal impurity being propane. Mass spectrographic analysis of the cylinder gas verified this and indicated no other impurity.

Hydrogen Chloride. The hydrogen chloride was C.P. grade, shown to contain, on mass spectrographic analysis, 5 to 10% ethylene and some ethyl chloride as impurities, all of which were completely removed by the activated-alumina trap following the hydrogen chloride cylinder.

Catalyst. The catalyst was activated alumina Alcoa Grade H-41. The 4 to 8 mesh granular particles were ground and screened, and the −20 +28 mesh material was retained for the kinetic study. The catalyst was activated by heating in a furnace at 750° F. for 16 hr.

Heat-transfer Material. An inactive form of alumina was obtained in the form of ¼-in. balls. These were ground and screened. The 20 to 28 mesh size was used as catalyst diluent, and the 20 to 16 mesh size was used as heat-transfer material in the preheating section of the reactor and as a catalyst support in the lower section of the reactor.

Experimental Procedure

The calculated highly exothermic nature of the reaction was experimentally verified during the preliminary stages of the work. Extreme radial and axial temperature gradients were present when an undiluted catalyst charge was used. At temperatures of operation over 100° C., the catalyst became coated with a deposit that varied in color from orange to black, and the activity of the catalyst decreased rapidly. Although considerable effort was expended in trying to obtain a constant catalyst activity, this was never achieved. It is believed that the decreasing activity was due to a slow deposition of polymer product from the propylene on the catalytic surfaces. When the catalyst was diluted with inert tubular alumina (volume of catalyst to volume of diluent of 0.4), the axial and radial temperature differentials were reduced to less than 10° C. With the improved temperature control, the rate of decrease of catalyst activity was markedly decreased, and by making all runs over a period of 4 to 6 hr. for each change in variables, the activity-time relationship could be obtained.

To initiate a run, the propylene flow was started first to prevent the water in the gas-washing bottles from backing into the system when the hydrogen chloride was introduced. Zero time was taken as the instant that propylene started to flow through the system. The hydrogen chloride was slowly introduced into the system so that the catalyst temperature did not rise above 40° C. The flow rates of the feed gases were adjusted within 10 min., and the reactor was brought to the desired temperature within 45 min. under carefully controlled conditions, so that there was a period of at least 15 min. of steady-state operation before the first sample was taken 1 hr. from the start-up time.

Analytical. A known volume of sample gas was transferred to the absorption tube from the gas buret and was reacted with water until no further change in gas volume occurred. The acid solution was then drained into the reservoir bottle and the absorption tube washed twice with approximately 10-cu.cm. portions of distilled water, which, in turn, were drained into the reservoir bottle. The acid solution was titrated with 0.05 *N* sodium hydroxide, using bromothymol blue indicator. The product-gas analysis could then be calculated by a material balance since the feed composition and volume of sample were known. In each case, three analyses were made for each point to obtain the best value for the gas composition.

TABLE 1.—THERMODYNAMIC PROPERTIES

	$S°$ 298.1	$H_f°$ 298.1
HCl	44.66 ± 0.01 EU (5)	−22,060 cal./gram mole (1)
Propylene	63.80 EU (4)	4879 cal./gram mole (4)
Isopropyl chloride	70.5 EU (6)	−31,200 cal./gram mole (6)

NOTE: For propylene and isopropyl chloride, the heat-capacity–temperature equation was estimated by the method of Watson *et al.* (6) and checked by the method of Dobratz (3). The heat-capacity–temperature equation for HCl is given by Bryant (2).

Experimental Results

Runs were made at a constant feed-gas rate of 0.032 gram mole/min. with slight variations due to pressure differences, using 2, 3, and 4 grams of catalyst. Activity-time relationships were obtained for feed compositions of 37% hydrogen chloride and 63% propylene, and 66% hydrogen chloride and 34% propylene at reaction temperatures of 44° and 80° C. A supplemental series of runs was made with a feed gas of 19% hydrogen chloride and 81% propylene at 60° C.

When the experimental data, an example of which is shown in Table 2, are plotted as moles of propylene-hydrogen chloride/mole of feed vs. process time after an initial unsteady period, the best straight line, drawn through the linear portion of the curve obtained for each run, was extrapolated to zero time in order that a correlation of the data might be made on a comparable basis. The values of the conversion (moles of propylene-hydrogen chloride/mole of feed) at various time factors (grams of catalyst × hr./gram mole of feed) as plotted in Figures 2 through 8 were obtained from these straight lines for process times of 0, 3, and 6 hr. The data plotted in Figures 9 through 15 were also obtained from these lines. The conversion obtained at process time of 0 hr. is available in Table 3 and will be of value in reproducing the original conversion-vs.-process-time curves of the authors.

Determination of Mechanism

Mass Transfer. The film thicknesses at the catalyst surface due to mass transfer were estimated for data at 80° C. by the method outlined by Yang and Hougen (*16*). The largest partial pressure difference across the film was found to be in the order of magnitude of 0.0002 atm. Following this procedure, it may be assumed that the effect of mass transfer was negligible and that the concentrations at the catalyst surface were the same as the concentration in the fluid stream.

Adsorption of a Reactant Controlling. The adsorption of neither the hydrogen chloride nor the propylene was the rate-controlling mechanism and was shown by applying initial-rate data to equations developed from those given by Hougen and Watson (*9*). Details of the procedure may be found elsewhere (*17*).

Desorption of Isopropyl Chloride Controlling. When the desorption of isopropyl chloride is the controlling step, the following rate equation applies (*9*):

$$r = \frac{k_{C_3H_7Cl} L K \left(a_{HCl} a_{C_3H_6} - \frac{a_{C_3H_7Cl}}{K} \right)}{1 + a_{HCl} K_{HCl} + a_{C_3H_6} K_{C_3H_6} + a_{HCl} a_{C_3H_6} K_{C_3H_7Cl} K} \qquad (1)$$

If only the initial rate is considered and the equation expressed in terms of mole fraction of hydrogen chloride, the following expression is obtained:

$$\frac{y_{HCl}(1 - y_{HCl})}{r_o} = -\frac{K_{C_3H_7Cl}}{k_{C_3H_7Cl} L} y_{HCl}^2 + \frac{K_{HCl} - K_{C_3H_6} + \pi K_{C_3H_7Cl} K}{\pi k_{C_3H_7Cl} L K} y_{HCl} + \frac{1 + \pi K_{C_3H_6}}{\pi^2 k_{C_3H_7Cl} L K}$$

$$\frac{y_{HCl}(1 - y_{HCl})}{r_o} = \alpha y_{HCl}^2 + \beta y_{HCl} + \gamma \qquad (2)$$

The constants in Equation (2) were evaluated with the initial rate data at

TABLE 2.—EXPERIMENTAL DATA FOR SERIES I, RUN 1

(These data are presented as typical of the type of information on which Figures 2 through 8 are based.)

Flow rate = 0.032 gram mole/min.
Time factor = 1.04 grams catalyst (hr./mole of feed)
Total pressure = 78.9 cm. Hg
Feed composition = 37% HCl, 63% C_3H_6

Time, hr.	Product composition, mole fraction			Conversion, moles C_3H_7Cl/mole feed
	HCl	C_3H_6	C_3H_7Cl	
0.75	0.326	0.603	0.071	0.066
1.75	0.342	0.613	0.046	0.044
2.75	0.344	0.613	0.043	0.041
3.92	0.345	0.613	0.042	0.040
5.00	0.345	0.614	0.041	0.039
6.75	0.348	0.616	0.036	0.035

60° C. The final equation is as follows:

$$\frac{y_{HCl}(1-y_{HCl})}{r_o} = -7.12y_{Ao}^2 + 6.64y_{Ao} + 1.335 \quad (3)$$

Since the signs of the constants α, β, and γ are in agreement with those of Equation (2), the desorption of isopropyl chloride is a possible controlling mechanism.

Surface Reaction Controlling. When the surface reaction controls, the following rate equation can be developed (9):

$$r = \frac{ksLK_{HCl}K_{C_3H_6}\left(a_{HCl}a_{C_3H_6} - \frac{a_{C_3H_7Cl}}{K}\right)}{(1 + a_{HCl}K_{HCl} + a_{C_3H_6}K_{C_3H_6} + a_{C_3H_7Cl}K_{C_3H_7Cl})^2} \quad (4)$$

If the activities are expressed in terms of mole fraction of hydrogen chloride and if only the initial rate is considered, the following equation is obtained:

$$\left[\frac{y_{HCl}(1-y_{HCl})}{r_o}\right]^{1/2} = \frac{K_{HCl} - K_{C_3H_6}}{(kaLK_{HCl}K_{C_3H_6})^{1/2}} y_{HCl} + \frac{1 + \pi K_{C_3H_6}}{(\pi^2 ksLK_{HCl}K_{C_3H_6})^{1/2}}$$

$$\left[\frac{y_{HCl}(1-y_{HCl})}{r_o}\right]^{1/2} = \alpha y_{HCl} + \beta \quad (5)$$

When the variables indicated in Equation (5) were plotted and straight lines drawn through the experimental points, these lines had either positive or zero slopes and positive intercepts. Since this is consistent with the constants in Equation (5), the surface reaction is a possible controlling mechanism.

Correlation of Kinetic Data

The kinetic data for the addition of hydrogen chloride to propylene over activated alumina were correlated by two equations assuming that the surface reaction is the rate-controlling step.

Solution A. In Equation (4), if the activities are replaced by mole fractions and the equation is rearranged, the following expression results:

$$\left[\frac{y_{HCl}y_{C_3H_6} - \frac{y_{C_3H_7Cl}}{\pi K}}{r}\right]^{1/2} = \frac{1}{\pi(ksLK_{HCl}K_{C_3H_6})^{1/2}} + \frac{K_{HCl}^{1/2}}{(ksLK_{C_3H_6})^{1/2}} y_{HCl} + \frac{K_{C_3H_6}^{1/2}}{(ksLK_{HCl})^{1/2}} y_{C_3H_6} + \frac{K_{C_3H_7Cl}}{(ksLK_{HCl}K_{C_3H_6})^{1/2}} y_{C_3H_7Cl}$$

or

$$R = \alpha + \beta y_{HCl} + \gamma y_{C_3H_6} + \delta y_{C_3H_7Cl} \quad (6)$$

where α, β, γ, and δ are the constant terms of the foregoing equations. The mole fraction of isopropyl chloride can be expressed in terms of the mole fractions of the other two components of the system, and the constants combined to give the following equation:

$$R = (\alpha + \delta) + (\beta - \gamma)y_{HCl} + (\gamma - \delta)y_{C_3H_6}$$

$$R = A + By_{HCl} + Cy_{C_3H_6} \quad (7)$$

where

$$A = \frac{1}{(ksLK_{HCl}K_{C_3H_6})^{1/2}}(1/\pi + K_{C_3H_7Cl})$$

$$B = \frac{1}{(ksLK_{HCl}K_{C_3H_6})^{1/2}}(K_{HCl} - K_{C_3H_7Cl})$$

$$C = \frac{1}{(ksLK_{HCl}K_{C_3H_6})^{1/2}}(K_{C_3H_6} - K_{C_3H_7Cl})$$

Upon evaluating the constants A, B, and C by the method of least squares from the experimental conversion-vs.-time-factor curves for all three temperatures, it was found that the signs of the constants were in all cases consistent with the definitions above.

In a steady-flow system the relationship between conversion and time factor can be obtained by the integration of the equation

$$R = \left[\frac{y_{HCl}y_{C_3H_6} - \frac{y_{C_3H_7Cl}}{\pi K}}{r}\right]^{1/2} \quad (8)$$

$$\frac{W}{F} = \int_o^x \frac{dx}{r}. \quad (9)$$

Graphical integration of this equation was carried out using the values of the constants A, B, and C obtained by the method of least squares. The values of the constants were adjusted by trial and error and the integration was repeated until an equation for the reaction rate was found that would best fit the experimental data. The final integrated conversion curves together with the experimental data are shown in Figures 2 through 8 for the various feed compositions at process times of 0, 3, and 6 hr.

The final values of each of the constants were found to be linear functions of both process time and temperature. Consequently, a simple equation was obtained for each constant as a function of process time τ, in hours, and temperature t, in degrees Centigrade:

$$A = (0.330 - 0.011t)\tau - 1.32 + 0.100t$$

$$B = (0.0128t - 0.351)\tau + 5.78 - 0.148t$$

$$C = (0.0136t - 0.415)\tau + 4.82 - 0.131t \quad (10)$$

Values of the constants calculated by these equations are compared with the experimental values in Table 4.

Solution B. Wynkoop and Wilhelm (15) have developed a rate equation for the reaction $A + B \rightarrow C$ by expressing the surface concentration of the reactants in the form of Langmuir adsorption isotherms. For the reaction which they studied, some simplifying assumptions could be made which led to an equation that could be integrated over a flow reactor. However, for reversible reaction where the fraction of the surface covered θ is expressed by the isotherm

$$\theta_i = \frac{a_i p_i}{1 + a_i p_i}$$

the rate equation is complicated and the constants are difficult to evaluate. For reaction $A + B \rightleftarrows C$, if the fraction of surface covered for each component of the system may be expressed as $\theta_i = a_i p_i$, a simplified rate equation may be derived:

$$\frac{d(Fy_c)}{dW} = Ka_Aa_B\pi^2 y_A y_B - k'a_C\pi y_C \quad (11)$$

Following the procedure outlined by Wynkoop and Wilhelm (15), this equation can be expressed in terms of only y_A and y_{Ao}, the mole fraction of A in the feed gas. The resulting equation becomes

$$F_o\frac{dy_A}{dW} = k'a_C\pi\frac{(1-y_A)^2}{(1-y_{Ao})^2}(y_{Ao} - y_A) - ka_Aa_B\pi^2 y_A\frac{(1-y_A)^2}{(1-y_{Ao})^2}(1 + y_Ay_{Ao} - 2y_{Ao}) \quad (12)$$

The term $F_o\, dy_A/dW$ is the slope of the curve when the mole fraction y_A is plotted vs. W/F for a constant feed rate. By indicating this slope by R, combining the constants, and rearranging, the following expression is obtained:

$$\frac{1}{R}\frac{(1-y_A)^2}{(1-y_{Ao})^2}(y_{Ao}-y_A) = \frac{B}{A}\frac{y_A}{R}\frac{(1-y_A)^2}{(1-y_{Ao})^2}(1-2y_{Ao}+y_Ay_{Ao}) + \frac{1}{A} \qquad (13)$$

where

$$A = k'a_C\pi$$

$$B = ka_Aa_B\pi^2$$

A plot of the two variable terms

$$\frac{1}{R}\frac{(1-y_A)^2}{(1-y_{Ao})^2}(y_{Ao}-y_A)$$

vs.

$$\frac{y_A}{R}\frac{(1-y_A)^2}{(1-y_{Ao})^2}(1-2y_{Ao}+y_Ay_{Ao})$$

should be a straight line if the assumptions which were made are valid. The slope and intercept of this line permit the evaluation of the reaction-velocity constants.

From the experimental data plotted as y_{HCl} vs. time factor W/F, the variable terms of Equation (13) were plotted and the best straight lines drawn through the points. The constants A and B were evaluated from the slopes and the intercepts, and Equation (12) integrated graphically to check the experimental data. The results of these integrations for the various feed compositions at process times of 0, 3, and 6 hr. are shown in Figures 9 through 15 together with the experimental points.

TABLE 4.—CALCULATED AND EXPERIMENTAL VALUES OF CONSTANTS *A*, *B*, AND *C*

$$r = \frac{\left(y_{HCl}y_{C_2H_2} - \frac{y_{C_2H_3Cl}}{\sigma K}\right)}{(A + By_{HCl} + Cy_{C_2H_2})^2}$$

	80° C.			60° C.			44° C.		
	Exp	Calc.	Dev.	Exp.	Calc.	Dev.	Exp.	Calc.	Dev.
Process time, 0 hr.									
A	6.65	6.68	+0.03	4.68	4.68	0.00	3.07	3.08	+0.01
B	−6.05	−6.06	−0.01	−3.12	−3.10	+0.2	−0.78	−0.73	0.00
C	−5.68	−5.66	+0.02	−3.00	−3.04	−0.04	−0.96	−0.94	+0.02
Process time, 3 hr.									
A	5.04	5.01	−0.03	3.60	3.67	+0.07	2.58	2.61	+0.03
B	−3.97	−4.04	+0.07	−1.90	−1.95	+0.05	−0.04	−0.09	−0.05
C	−3.70	−3.64	+0.06	−1.80	−1.84	−0.04	−0.25	−0.39	−0.04
Process time, 6 hr.									
A	3.20	3.23	+0.03	2.65	2.66	+0.01	2.05	2.16	+0.11
B	−1.93	−2.02	−0.09	−0.70	−0.60	+0.10	0.72	0.54	−0.18
C	−1.68	−1.62	+0.06	−0.60	−0.63	−0.03	0.17	0.16	−0.01

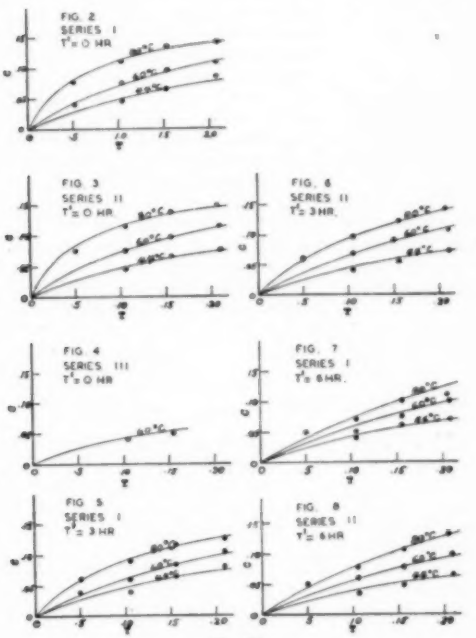

Fig. 2-8.
Conversion vs. time factor

C = Conversion $\left(\frac{\text{moles } C_2H_7Cl}{\text{mole feed}}\right)$

T = Time factor $\left(\frac{\text{g. catalyst}}{\text{moles of feed/hr.}}\right)$

T' = Process time (hr.)

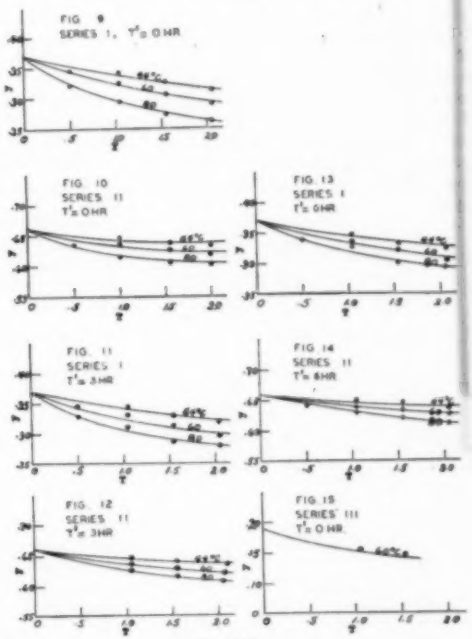

Fig. 9-15.
Mole fraction HCl vs. time factor.

y = Mole fraction HCl

T = Time factor

T' = Process time

Series I Feed Comp. 37% HCl, 63% C_2H_2
II Feed Comp. 66% HCl, 34% C_2H_2
III Feed Comp. 19% HCl, 81% C_2H_2

TABLE 5.—VALUES OF A AND E IN ARRHENIUS EQUATION

$$k = Ae^{-\frac{E}{RT}}$$

Process time	ka_Aa_B E, K. cal. / gram mole	ka_Aa_B A, gram mole / gram cat. × hr.	$k'a_C$ E, K. cal. / gram mole	$k'a_C$ A, gram mole / gram cat. × hr.
0	8.02	6.64×10^4	11.80	1.25×10^7
3	6.98	1.13×10^4	11.02	3.03×10^6
6	5.48	9.48×10^2	8.56	4.58×10^4

TABLE 6.—CALCULATED AND EXPERIMENTAL VALUES OF THE REACTION VELOCITY CONSTANTS ka_Aa_B AND $k'a_C$

	80° C.			60° C.			44° C.		
	Exp.	Calc.	Dev.	Exp.	Calc.	Dev.	Exp.	Calc.	Dev.
				Process time, 0 hr.					
ka_Aa_B	0.736	0.706	−0.030	0.342	0.361	+0.019	0.198	0.190	−0.008
$k'a_C$	0.577	0.583	+0.006	0.241	0.239	−0.002	0.083	0.111	+0.028
				Process time, 3 hr.					
ka_Aa_B	0.538	0.520	−0.018	0.302	0.300	−0.002	0.176	0.158	−0.018
$k'a_C$	0.420	0.384	−0.036	0.214	0.170	−0.045	0.076	0.082	+0.006
				Process time, 6 hr.					
ka_Aa_B	0.364	0.333	−0.031	0.244	0.240	−0.004	0.151	0.126	−0.025
$k'a_C$	0.208	0.185	−0.023	0.114	0.101	−0.013	0.058	0.053	−0.005

The constants ka_Aa_B and $k'a_C$ are plotted vs. reciprocal absolute temperature in Figures 16 and 17 and the values of the frequency factor and activation energy of the Arrhenius equation and are shown in Table 5 for each constant. From the relationship between the velocity constants, process time, and temperature in degrees Kelvin, the following empirical expressions were developed:

$$ka_Aa_B = 6.64 \times 10^4 e^{-\frac{8020}{RT}} - 9.29 \times 10^{-11} \tau e^{0.05767}$$

$$k'a_C = 8.91 \times 10^5 e^{-\frac{10,000}{RT}} - 6.00 \times 10^{-10} \tau e^{0.0524T} \quad (14)$$

The values of the constants calculated by Equation (14) are compared with the experimental values in Table 6.

Discussion of Results

From Figures 2 through 15 it can be seen that both methods of correlation give satisfactory agreement with the experimental data. Solution A possibly is the better of the two since the agreement is better throughout the range of time factors in most cases. This is especially true at process times other than zero hour. By comparing Figures 4 and 15 it can be seen that the solutions give essentially the same results when used with a feed composition of 19% hydrogen chloride. The fact that Solution B is only an empirical equation is indicated by the value of the ratio $ka_Aa_B/k'a_C$. From Equation (11) it can be seen that this ratio should be the over-all equilibrium constant if the surface reaction were the controlling step.

In Table 7 the ratio $ka_Aa_B/k'a_C$ is compared with the value of the over-all equilibrium constant K, as calculated from the thermodynamic properties of the constituents of the system. Although the ratios are nearly the same at the different process times, the variation of the ratio with temperature does not correspond to the variation of the equilibrium constant with temperature. Thus, the original assumption as to the expressions for the adsorption isotherms are probably not correct for these components. Solution A incorporates the equilibrium constant when evaluating the reaction constants so that a similar comparison cannot be made.

Although the reaction-velocity constant and the individual adsorption constants of Equation (4) cannot be evaluated with these data, conclusions of a general nature may be drawn. Referring to Table 4, it can be seen that the ratio of B to C is approximately 1:1 in nearly every case. This would indicate that the values of the adsorption equilibrium constants K_{HCl} and $K_{C_3H_6}$ are nearly equal, with K_{HCl} being slightly larger. This is substantiated by the results obtained when only the initial rates were considered. Also, since B and C are usually negative, $K_{C_3H_7Cl}$ must be larger than either K_{HCl} or $K_{C_3H_6}$. The fact that A increases while B and C become more negative with increased temperature would indicate that $K_{C_3H_7Cl}$ increases with increased temperature at a faster rate than $(ksLK_{HCl}K_{C_3H_6})^{1/2}$ and also at a faster rate than either K_{HCl} or $K_{C_3H_6}$.

Proper interpretation of the effect of process time on the values of the con-

TABLE 7.—VALUES OF $ka_Aa_B/k'a_C$ AND THE EQUILIBRIUM CONSTANT K

	Process time: 0 hr.			3 hr.			6 hr.		
°C.	80	60	44	80	60	44	80	60	44
$ka_Aa_B/k'a_C$	1.28	1.43	2.39	1.28	1.41	2.32	1.75	2.14	2.60
K	2.32	7.61	22.4	2.32	7.61	22.4	2.32	7.61	22.4

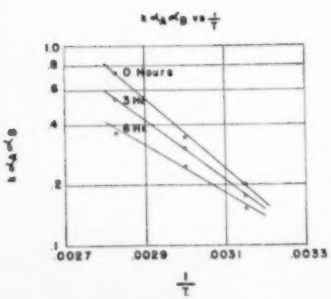

Fig. 16

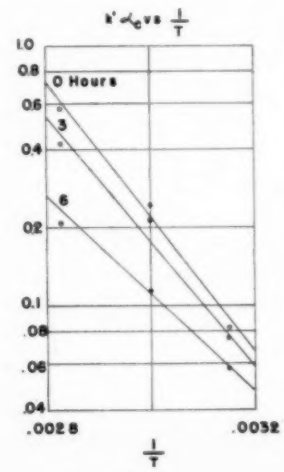

Fig. 17.

stants A, B and C is not apparent from their definitions. The effect of fouling of a catalyst may be introduced into the rate equations in either of two ways. First, a fouling factor may be introduced as a multiplying factor in the reaction-velocity constant ksL, considering that fouling merely reduces L, the total number of active centers on the catalyst surface. The second method is the introduction of another term in the denominator, or adsorption term, of Equation (4) with the view that fouling has the same effect as the adsorption of a constituent on the active centers. This latter procedure has been used most successfully (*10*). In either case the fouling factor would be a function of temperature, conversion, and process-period length.

If the first method of correcting for catalyst fouling were applicable in this case, the absolute values of all three constants should increase with process time. Since this is not the case, the first method does not apply to the reaction constants obtained in the correlation by solution *A*. However, the reaction constants $k a_A a_B$ and $k' a_C$ do decrease with time, indicating that this type of correction is applicable in the case of Solution *B*.

From Equations (4) and (8) it can be shown that the following is an identity:

$$A + By_A + Cy_B = \frac{1}{(ksLK_AK_B)^{1/2}}\left(\frac{1}{\pi} + y_AK_A + y_BK_B + y_BK_C\right) \quad (15)$$

According to the second method of introducing a fouling factor, a term J, which is a function of conversion, temperature, and time, can be introduced into the adsorption term in the right-hand side of Equation (15). Eliminating y_B, the equation becomes:

$$A + By_A + Cy_B = \frac{1}{(ksLK_AK_B)^{1/2}}\left[\left(\frac{1}{\pi} + K_C\right) + (K_A - K_C)y_A + (K_B - K_C)y_B + J\right] \quad (16)$$

Each of the terms in Equation (16) is a function of temperature; J is a function of y_A, y_B, and time as well as temperature.

If the expressions for A, B, and C given by Equation (10) are substituted into the left-hand side of Equation (16) and the terms rearranged, the following expression results:

$$A + By_{HCl} + Cy_{C_3H_6} = (-1.32 + 0.100t) + (5.78 - 0.148t)y_{HCl} + (4.82 - 0.131t)y_{C_3H_6} + [(0.330 - 0.0111t) + (0.0128t - 0.351)y_{HCl} + (0.0136t - 0.415)y_{C_3H_6}]\pi. \quad (17)$$

Since Equations (16) and (17) are of the same form, this method of introducing the effect of catalyst fouling applies in this case.

Conclusions

On the basis of this kinetic study of the catalytic vapor-phase addition of hydrogen chloride to propylene over activated alumina, the following conclusions can be made.

1. Over the temperature range 44° to 80° C. isopropyl chloride is the only product present in the exit gases.
2. The activity of activated alumina as a catalyst for this reaction decreases with time.
3. The rate of reaction may be controlled either by the desorption of isopropyl chloride or by the surface reaction between adsorbed molecules of hydrogen chloride and adsorbed molecules of propylene.
4. The rate of reaction may be expressed as a function of the composition of the gas phase and certain design constants. Furthermore, the variation of these constants with time may be evaluated to give the rate of decrease of catalyst activity with time. The equations developed hold quite well in the range of approximately 1:3 molal ratio HCl to propylene in the feed to 3:1 molal ratio of HCl to propylene in the feed.

Notation

A, B, C = constants

a_A, a_B, a_C = gas-phase activities of components A, B, and C

F = flow rate of feed, gram moles/unit time

J = fouling factor

K_A, K_B, K_C = adsorption equilibrium constants

K = over-all equilibrium constants

k, k' = reaction-velocity constants for the surface reaction

k_A, k'_A = reaction-velocity constants for the adsorption reaction

L = number of active centers/unit mass of catalyst

r = rate of reaction, gram moles converted/(unit time)(unit mass of catalyst)

s = number of equidistant adjacent active centers

T = temperature, ° K.

t = temperature, ° C.

W = mass of catalyst

x = moles of reactant converted/mole of feed

y = mole fraction

Greek Symbols:

$\alpha, \beta, \gamma, \delta$ = constants

θ = fraction of total active centers

π = total pressure, atm.

τ = time, hr.

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INDUSTRIAL VIEWPOINTS ON SEPARATION PROCESSES

PART II

Part I appeared in October issue, p. 523.
Part III will be run in an early issue.

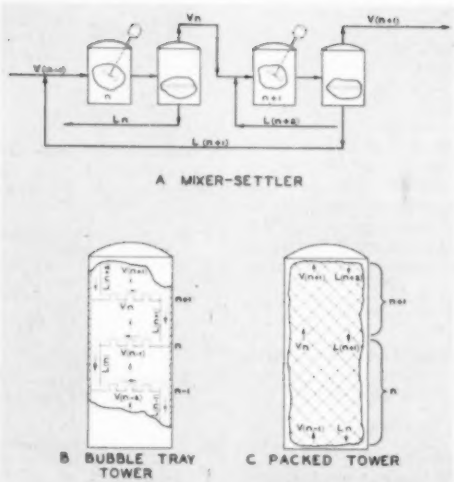


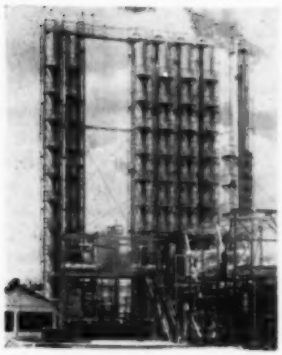
FIG. 5 TYPICAL SECTIONS OF SEPARATION UNITS

THE preceding generalizations can be applied with considerable accuracy to fractional distillations. This situation is a result of the approximate constancy throughout a fractionator of the α factor, and the approximately equal molal rate of liquid flow at different levels in a column between points where heat or material is added or abstracted. Wherever this situation is found in any type of separation process, these same generalizations can be applied. In most separations, neither the α nor the liquid flow rate (or its equivalent) remains constant.

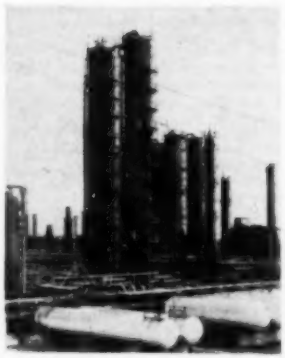
Figure 5 illustrates typical sections of the kind of separation units considered in this study. Variations of these three types are found in industry but all industrial units of importance use arrangements resembling one or the other of these three. (Differential vaporization and condensation methods have not been included.) Figure 5(A) shows the mixer-settler arrangement where the energy for contacting is derived from an outside source. Figure 5(B) illustrates a bubble-tray tower where the expansion of the vapor furnishes the contacting energy. Figure 5(C) represents a packed tower or a spray tower where part or nearly all the energy for contacting is derived from gravity. Phases in each stage of a mixer-settler arrangement can be made to approach equilibrium very closely so that each mixer can be counted as one equilibrium step. In a bubble-tray tower, more than one, or sometimes somewhat less than one actual bubble tray is equivalent to one equilibrium step. In a packed or spray tower, some length of tower will give separations approximating one equilibrium step. For purposes of calculation each separation unit is assumed to be divisible into some finite number of equilibrium steps. An equilibrium step is defined to be that number of sub-units or length of a tower required to produce

K. H. Hachmuth

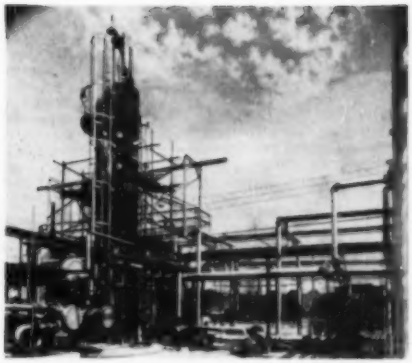
Karl H. Hachmuth was graduated from the University of Michigan with a B.S. degree in chemical engineering. He spent his first professional years working in manufactured-gas plants and as a development chemist for the Ozokerite Mining Co. He joined the Phillips Petroleum Co. in 1927 as a chemical engineer, serving successively as research engineer, group leader, section chief, associate director of research, technical consultant in chemical engineering, and member of the Research Planning Board, which position he now occupies. Hachmuth is known for his contributions to phase equilibria, thermodynamics, and the mathematical analysis of chemical engineering problems.



A group of fractionators used for separating high purity hydrocarbons from straight run and natural gasolines. Some of the products: 99.6% purity iso-octane, 99.5% purity n-heptane, 85% purity cyclohexane.



Extractive distillation unit (twin towers in foreground) 13 ft. diam. by 145 ft. tall. This unit separates between n-butane and 2-butenes in Plains butadiene plant of R. F. C.



A 4-ft. diam., 30 ft. tall experimental contacting unit with auxiliary equipment for studying the performance of bubble trays and other contacting devices in vapor-liquid and liquid-liquid service.

a light phase leaving, at one end, which is in equilibrium with a heavier phase leaving, at the other end, of the tower section. Any particular equilibrium step may be designated by the letter n. The next equilibrium step in the direction of flow of the lighter phase is then designated as $(n+1)$, the next as $(n+2)$ and so on. Counting equilibrium steps in the opposite direction, that is in the direction of flow of the heavier phase, the designations $(n-1)$, $(n-2)$, etc., are used.

The rate of flow of the light phase (usually in terms of pound moles per unit of time) is represented by the symbol V with an appropriate subscript designating the number of the equilibrium step from which the phase was derived, if such is significant. The heavier phase is represented by L similarly defined with appropriate subscripts.

The concentration of any component in the light phase is expressed as mole fraction y with a subscript indicating the particular component when necessary. The concentration of a component in the heavy phase is represented as x. Sometimes it is convenient to express concentrations in extraction towers on a solvent-free basis. The expressions (V), (L), (x) and (y) are used to denote this method of designation. The solvent concentration is expressed in the usual fashion so that $(V) = V(1-y_i)$ $(L) = L(1-x_i)$, etc., where the solvent is the i component.

Phase-equilibrium factors are expressed by the general term "equilibrium concentration ratio," K, which, for vapor-liquid equilibrium is called the equilibrium-vaporization ratio or sometimes, inappropriately, equilibrium-vaporization constant. This factor is defined as

$$K = \frac{y}{x}$$

or, on a solvent-free basis

$$(K) = \frac{(y)}{(x)}$$

Useful combinations of the L, K, and V factors are the absorption, A, and stripping, S, factors. These are defined as

$$A = \frac{L}{KV}, \qquad S = \frac{KV}{L}$$

Solvent-free factors can be similarly defined by solvent-free terms.

Two other generalizations are convenient in discussing difficult separations. Each complete separation unit may be divided into two functional sections. The primary purpose of one section, the absorption section, is to absorb or remove, from the stream which eventually leaves the product end of that section as a product stream, the less volatile (more soluble) (higher melting point) components. The purpose of the other section, the stripping section, is to strip or remove, from the stream which eventually leaves the product end of that section as a product stream, the more volatile (less soluble) (lower melting point) components. These are primary functions of these sections. As will be shown, either of these sections performs to some degree the same function as the opposite section. Some separation units consist of but one of these sections (gas absorbers, rich oil strippers, etc.).

All types of separations requiring countercurrent flow of two phases and more than a few equilibrium steps may be studied using the fundamental bases just outlined. There seems no reason to use a different system of symbols for fractional distillation, extractive distillation and solvent extraction as has been done by some authorities. Use of the same symbols clearly demonstrates the similarity of the processes. When more than two phases are present, some other means of distinguishing the several phases will be necessary. This is not, however, a normal situation in multistage, countercurrent flow separations.

Separation Calculations

Articles and books discussing methods for calculating multistage separation processes, particularly fractional distillation, abound. It is not the purpose of this article to review, even partially, the voluminous literature on this subject. The reader who wishes to obtain a detailed background may refer to the "Chemical Engineers' Handbook" (*26*), "Unit Operations" by Brown and associates (*2*), "Elements of Fractional Distillation," Robinson and Gilliland (*31*), "Distillation and Rectification," Kirschbaum (*18*), and to "The Separation of Gases," by Ruheman (*33*). These and many other reference books not only discuss various aspects of separation but also give references to original publications.

All calculation methods contain some assumptions which are not realized in actual

operation. The commonest assumption is that the two phases are contacted in a stepwise fashion and that every part of a phase leaving a contacting step has the same properties. Packed columns obviously do not operate in a stepwise fashion. However, if a packed column is separating a binary mixture there will be a length of contacting section from which the heavy phase leaving has a composition that is in equilibrium with the light phase leaving (providing there is no pressure drop). If a packed column is separating a complex mixture there is no reason to believe that the vapor at any point in the column, where three or more compounds are present, has a composition in equilibrium with the liquid at any other point.

A bubble-tray column does operate in a stepwise fashion but by no means do the vapors leaving a tray have a uniform composition. It is usually assumed that the average composition of the vapors leaving a bubble tray approaches to some definite extent equilibrium with the liquid leaving that tray or, an ideal or theoretical tray is assumed which is defined as an ideal equilibrium step. The number of ideal equilibrium steps found necessary is converted to the number of actual bubble trays required by multiplying by some factor determined by experience. Either of these methods can be made to give answers which will agree with operating experience when binary mixtures are being separated. Answers based on either of these assumptions cannot agree exactly with experience on multicomponent mixtures. The reason for failure to match multicomponent separations is that the several components do not approach equilibrium to the same degree in each contact step.

On first thought one might assume this varying degree of approach to equilibrium of little practical significance. Usually it can be ignored when the fractionating tower contains many contacting steps and the separation being made is sharp and between adjacent compounds (with respect to ease of separation) which are major constituents. If these conditions are not met then the difference between calculated separations and actual separations may be significant. The author had the opportunity of reviewing the results of some liquid-extraction experiments which brought out the difference between ideal equilibrium steps and actual performance.

A small solvent extraction unit of the spray type was being studied to determine its efficiency. Two tests were made on the unit using the same solvent but separating different mixtures. One mixture was a binary system for which the equilibrium data were accurately known. The other mixture was a typical gas oil containing many different compounds. The apparent number of ideal equilibrium steps could be uniquely determined by the usual type of calculation for the binary system but the complexity of the gas oil prevented any such analysis. Because a conversion factor was desired to estimate contacting efficiency when handling gas oil from efficiencies determined on the simpler binary system, it was decided to run a series of experiments which would conclusively show the separation obtained using one, two and three ideal equilibrium steps. This was done by stirring the solvent phase and oil phase together in a step-wise fashion for a long enough time per step to be sure equilibrium was obtained. The degree of separation was expressed by concentration of extract in the extract phase and aniline number. At 50% of capacity the spray tower performed as if it had 2.3 ideal equilibrium steps when judged by the concentration of extract in the extract phase and as if it had considerably more than three equilibrium steps when judged by the aniline point of the extract. At full capacity the apparent number of steps was 1.8 and 1.6, respectively. Not only did the two methods of judging equilibrium steps disagree but they changed their order of disagreement when the charge rate to the unit was changed.

Another common assumption made in fractionator calculations is that ratio of the quantity of vapor phase (expressed as moles per unit time) to quantity of liquid phase (similarly expressed) passing various planes throughout a section of column remains constant. This assumption is fairly well approximated in some separations but may be considerably in error for others. This difficulty is surmounted by the Ponchon method (*32*) for calculating the separation of a binary mixture but no such simple process is available for complex mixtures. A perfectionist must calculate such separations by the step-by-step method making tedious equilibrium and heat and material balance calculations for each step.

Most fractionators are calculated assuming constant pressure throughout although actual pressure drops are of the order of 1/10 lb./(sq.in.) (bubble tray) on fully loaded large towers operating at moderate pressures.

Finally, the phase-equilibrium data used may be in error. Only for mixtures consisting of fairly close boiling members of a homologous series can the equilibrium relationship be expressed as a function of temperature and pressure alone. Even then, pressures must be limited to values appreciably less than the critical pressures. More complex mixtures or high-pressure regions require knowledge of the effect of both the nature of the mixture and the concentration of the individual components on the equilibrium ratios for those components. This means that some assumptions must be made for the way in which all the components change, one with respect to the others, in the separation unit before equilibrium ratios can be estimated for use in calculating the separation.

Considering the uncertainties, calculation of a separation involving complex mixtures appears to be a rather inaccurate process. However, good answers can be obtained with a moderate amount of labor. More than that effort may be wasted because the greater precision obtained in the calculations is not justified by the accuracy of the assumptions. One wonders whether the effort expended in developing some of the more rigorous methods (in a mathematical sense) of solving distillation problems was justified when any answers obtained in practical design are but fair approximations.

The separation processes of most interest to the large-scale operator are the continuous or steady-state processes. In these processes conditions at any point of the system remain constant with time. No accumulation, neither loss of material nor energy takes place within the unit. Thus, for every pound of material entering, there must be a pound of material leaving. Furthermore, each individual component in the feed must appear in the products in quantities which add up to the amount fed. Similarly all the energy added to the system must be removed from the system. Ordinarily heat is the only type of energy considered because other energy, mainly represented by the loss of pressure or liquid head through the unit, is so small a portion of the total that it can be ignored. However, pressure losses should not be ignored in deeply refrigerated separations.

The industrial engineer is faced with three types of separation problems:

1. New plant design where he tries to design his separation steps to give optimum results.
2. Adapting existing equipment to a separation for which it was not designed. Here he must compromise between the desired separation and a practical separation possible on the equipment available.
3. Determining whether a piece of equipment is performing as it should or being operated in the most efficient fashion.

An understanding of the factors limiting performance of a separation unit will help a great deal in arriving at conclusive answers to these problems.

The industrial engineer instinctively realizes the necessity for heat and material balances on a complete unit but sometimes doesn't think of each part or section of his unit in the same way. The heat and material entering every section of a continuously operating unit must leave that section in equal amount. Oftener forgotten is the necessity for providing sufficient countercurrenting of the two phases being contacted to obtain the desired degree of separation. If a sufficiently large number of contacting steps has been provided, the degree of separation will be controlled by the amount of countercurrenting per unit feed. On the other hand, if an insufficient number of contacting steps has been provided, little improvement in separation will be obtained by countercurrenting beyond a certain degree. Put in other words, there is a minimum amount of countercurrenting and a min-

imum number of contacting steps required for any separation. If equipment is inadequate in either of these requirements, the separation cannot be made.

Kremser (*19*) and Brown and associates (*1, 4*) have developed the absorption factor method for calculating bubble-tray towers. This method is well fitted to permit approximate solutions of many types of separation problems. The following factors are used in the method:

Absorption factor for component i,

$$A_i = \frac{L}{K_i V}$$

Stripping factor for component i,

$$S_i = \frac{K_i V}{L}$$

If none of component i is in the liquid or heavier phase entering the absorption section of a separation unit Brown's formula (*1*) for absorption may be expressed as:

Fraction of component i absorbed =

$$\frac{A_i^{n+1} - A_i}{A_i^{n+1} - 1} \qquad (4)$$

Or fraction of component i not absorbed

$$= \frac{A_i - 1}{A_i^{n+1} - 1} \qquad (5)$$

Replacing the A's by S's gives the similar expressions for fraction stripped and not stripped.

The validity of these expressions depends on the A or S factors remaining constant throughout the section of tower being studied. Even if the A or S factor does not remain constant the answers obtained may approximate the ideal answer close enough for many purposes. For example, suppose there are three equilibrium stripping steps having S values of 1.1, 1.2, and 1.3 respectively. The expanded form of the formula for fraction not stripped is

$$\frac{1}{1 + S_3 + S_3S_2 + S_3S_2S_1}$$

which gives as an ideal answer 0.1794 as the fraction not stripped if the S values run in the sequence shown (increasing with number of steps counting upwardly) or an answer of 0.1947 if the S values decrease upwardly in usual fashion. If an arithmetic average of S of 1.2 is used and the condensed form for fraction not stripped $(S-1)/(S^{n+1}-1)$ is used the answer obtained is 0.1862. If the geometric mean $\sqrt{1.1 \times 1.3} = 1.196$ is used the answer is 0.1910. This agrees within 2% of the 0.1947 not stripped or within ½% when based on the fraction stripped. In this simple case the agreement is well within the usual uncertainties in equilibrium ratios and the difference between actual separation performance and the concept of ideal equilibrium steps on which the calculation is based. (The geometric mean is preferred to the arithmetic mean because it is more conservative, that is, requires more equilibrium steps for a given separation not because it happens to agree, in this example, more closely with the ideal answer.)

In many separations, particularly in liquid extraction, azeotropic distillation and, to a lesser extent, in extractive distillation the S and A factors remain fairly constant throughout large sections of the contacting towers. Even in ordinary fractional distillation these factors can be used with fair results two or three equilibrium steps away from the feed entry, reboiler and top of the column.

Two examples, one for azeotropic distillation and one for extractive distillation, are given in the next part of this article to demonstrate the use of the absorption and stripping factor method for calculating separations. The method reduces to finding the number of equilibrium steps required for stripping the more volatile (less soluble) key component from the material descending the tower from the feed entry and finding the number of equilibrium steps required above the feed entry to absorb the less volatile (more soluble) key component. Simultaneously the less volatile component must not be stripped from the bottom product to too great an extent nor the more volatile component absorbed in top part of the tower to too great an extent. Nonkey components are distributed between the top and bottom products according to their respective absorption and stripping factors. Figure 6 is an absorption factor chart which is convenient to use in these estimations. It covers a wider range of A and S factors than is usually found in these charts and, being logarithmic, gives about the same degree of precision throughout its range.

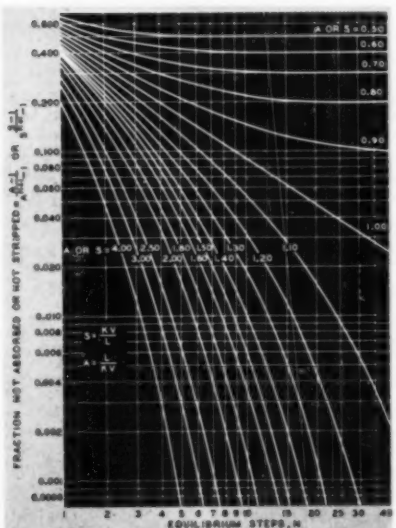
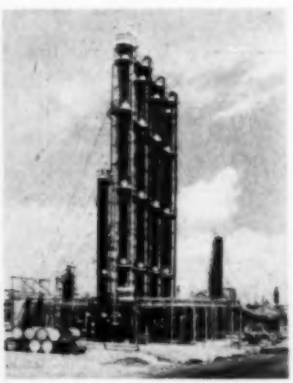
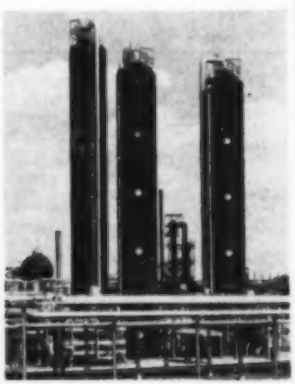

A OR S = 0.50
0.60
0.70
0.80
0.90
1.00
A OR S = 4.00 2.50 1.80 1.50 1.30 1.0
3.00 2.00 1.60 1.40 1.20
S = KV/L
A = L/KV
FRACTION NOT ABSORBED OR NOT STRIPPED = A^(n+1) − A / A^(n+1) − 1 OR S^(n+1) − S / S^(n+1) − 1
EQUILIBRIUM STEPS, N

FIG. 6 ABSORPTION FACTOR CHART



A group of five fractionating columns, 3 ft. and 4 ft. diam. with 25 or 50 bubble trays each, used to determine optimum operating conditions and product quality before starting commercial operation on a new separation.



Two sections of a "butane splitter" (separating between isobutane and n-butane) and a depropanizer (separating between propane and isobutane). Tower diameters 13 ft., heights 100 ft. and 120 ft.

The two examples given should be sufficient to suggest the manner in which this method can be employed for other separations. The particular separations used, azeotropic distillation and extractive distillation, were chosen because they seem to give many inexperienced engineers a feeling of helplessness when they face the necessity of solving one of these separation problems.

To avoid confusion, note that Brown and others use a formula containing the concentration of the component being absorbed (stripped) in equilibrium with its concentration in the entering absorbing (stripping) fluid as a limit which the extent of absorption (stripping) approaches. This requires a knowledge of the composition of the absorption or stripping fluid. This is not often known until after further calculations. If the composition is assumed, subsequent calculations must fit that assumption. Actually the presence of some of the material being absorbed in the absorption fluid has no effect on the amount of that material absorbed from the stream entering the other end of the absorption column. But it does have an effect on the composition of the light phase leaving the absorption section because part of the material entering with the absorption fluid will be stripped out and will appear in the light phase leaving the top of the section. Hence, if the amount of material being absorbed, which is present in the incoming absorption fluid is unknown but small, it can be ignored in the preliminary calculations. When its actual quantity is determined in later calculations its effect can be calculated by the stripping factor.

The true effect of such residual materials on recovery and purity are quite evident by this method of calculation. This procedure of studying each entering stream independently is valuable in analyzing complex separation processes. The good and bad effects of various methods of operating the process become clear compared to the confused picture which results when over-all performance is studied to determine advantageous changes.

Notation

A = absorption factor = $\frac{L}{KV}$

F = feed rate, moles per unit time

$H_i - H_i^\circ$ = differential heat of solution

K = phase equilibrium ratio $= \frac{y}{x}$

L = liquid rate = heavier phase rate of flow, moles per unit time

N = equilibrium step number

P = vapor pressure

R = fraction recovery (of a component in a product stream)

R = gas constant, used in Equation (9) only

S = stripping factor = $\frac{KV}{L}$

S_p = solvent entering with feed, moles per unit time

T = absolute temperature

V = vapor rate = lighter phase rate of flow, moles per unit time

(A) = absorption factor, solvent-free basis = $\frac{(L)}{(K)(V)}$

(K) = phase-equilibrium ratio, solvent-free basis = $\frac{(y)}{(x)}$

(L) = liquid rate, solvent-free basis

(S) = stripping factor, solvent-free basis = $\frac{(K)(V)}{(L)}$

(V) = vapor rate, solvent-free basis

ln = natural logarithm

x = concentration in heavier phase, mole fraction

y = concentration in lighter phase, mole fraction

(x) = concentration in heavier phase, solvent-free basis

(y) = concentration in lighter phase, solvent-free basis

π = total pressure on system

α = relative volatility

γ = activity coefficient

∂ = differential operator

Δ_x = change in x concentration per equilibrium step

Δ_i = moles i passing a given point per unit time in lighter countercurrent stream minus moles i passing same point per unit time in heavier stream

$\Delta\Sigma_{i,j,k}$ = total moles in lighter stream minus total moles in heavier countercurrent stream passing a given point per unit time

SUBSCRIPTS:

H = n-heptane

P = pressure

T = toluene

x = concentration

i = component i

j = component j

k = component k

n = equilibrium step number

s = solvent

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ORGANIZATION | ADMINISTRATION

Of Chemical Market Research

IF chemical market research is defined as the determination and evaluation of all pertinent facts concerning chemical markets and marketing for use by management in establishing policies and programs or, more briefly, chemical-market fact finding for management action, then it may be a function of a business enterprise itself, or it may be a consulting function. This condition is determined by the magnitude of the specific task, its duration, the need for anonymity, or the need for an independent viewpoint.

This paper is concerned primarily with chemical market research as a function of the business enterprise itself, but in many instances this work might better be done by outside consultants, of whom there are now a number well qualified in this field.

Policy

Before it can determine its policy on chemical market research, management must first determine the needs of the business and arrive at answers to some important questions:

1. Is the need for chemical market research temporary or permanent? If it is needed to find the answers to only a few specific problems, then this work might better be done by an outside agency.
2. What volume of chemical market research work is required? Upon the findings of the market research director may depend many critical management decisions. Good chemical market research is insurance; bad market research can be fatal to the enterprise. If the volume of chemical market research work is insufficient to attract, support, and provide opportunity for a high-caliber market research director and staff, this work should be done by a qualified consultant.
3. What are the objectives in employing chemical market research? If chemical market research is wanted to provide facts on which day-to-day decisions of management may be based, then the establishment of a market research department is well justified, assuming of course that the volume of work is sufficient, as indicated earlier.

   If, however, chemical market research is wanted to appraise company projects for the purpose of interesting the investment of outside capital, consideration should be given to having this work done—or at least verified—by an outside consultant. While the company chemical market research director usually is entirely objective in his findings, investors may feel that the company-employed director may be prejudiced in favor of the project.

Program

Assuming that a chemical market research department is required within the enterprise, management must then determine in broad terms what this department is expected to do. Too often, management, having some immediate need for a certain type of chemical market research, may hastily set up a department to handle the specific task of the moment, without regard for the other services which chemical market research can and should perform, thus handicapping itself in the beginning. Some questions which should be considered in this connection are (1) is market research wanted for work on new products only, or (2) is it wanted to work exclusively on marketing problems connected with existing products, or (3) is chemical market research to be used to its full capacity and serve all major functions of the business? Obviously, enlightened management will want to use chemical market research to its maximum potential at the outset, but only after management has determined on its policy can it attempt to establish the program in broad terms. The program for an all-inclusive chemical market research department should be outlined in general terms, by answering such questions as: How much work is required on new products? How much work is to be done on existing products? How much work will be required in as-

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sisting production, traffic, inventory-control, financial, sales, research and other departments of the enterprise? How much work in an advisory capacity is required for top management?

Organization

If chemical market research is required exclusively for work on new products, it might be assumed that this department should be placed under the director of research and development. If research is wanted only on existing products, this department might be placed under the director of sales. If, however, chemical market research is to serve all departments of the business impartially and maintain an objective viewpoint, it must report to the top operating executive only.

In some instances, chemical market research has been appended to the sales or research and development department, an arrangement that frequently results in overconcentration on one phase of the business and consequent loss of objectivity.

Since chemical market research by its very definition is a staff function, and its duties require that it be coldly objective and impartial in its work, it is the writer's firm opinion that its only logical place in the business structure is directly under, and reporting only to, the chief operating officer of the company. In this position, it can serve impartially all departments of the enterprise, and its objectivity is less likely to be impaired by any personal ambitions of the chemical market research director or his superior.

The organization of the department will depend largely on the type of markets to be investigated and the extent of the work to be done. In its simplest form, the chemical market research department will consist of a director and a secretary. The director will plan the work, collect the statistical data, carry out the field work, interpret the data, and prepare and present the final report. As the work grows, a statistician may be added. In this case, the statistician would collect the statistical material, interpret it, assist the director in interpreting the data gathered in the field, and assist in preparing the final report. To this organization may later be added a cartographer for charting and diagram work.

As the need for field work increases, a field staff may be added, reporting to the director. The director is thereby relieved of much of the leg work of routine contacts, but it still remains his responsibility to plan the work of the field staff and statistician, to interpret the data collected, and to prepare and submit the final report. It is frequently desirable to assign individual problems to members of the field staff, in which case, the field man has the full responsibility for gathering the data, correlating it with the statistical material, interpreting it, and preparing the final report under the director's guidance. This plan may later lead to the employment of juniors working under the senior field men.

There is some advantage, particularly on manufacturer's-goods projects, in having one man do all the work on a single project, as there is a "feel," an intuitive grasp of the circumstances, which comes only when a single individual has all the facts, and this is particularly valuable.

Chemical market research on manufacturer's goods seldom requires a senior-junior field set-up, but consumer-goods research, requiring as it does a large number of people for field contacts, may make this type of organization desirable. In some cases, the juniors may be temporary or part-time employees for consumer's-goods work.

If the organization grows further, it may then become necessary to employ an assistant director, whose duty it is to supervise the field forces, relieving the director of this supervisory burden and assisting in the preparation of the final report.

As the organization achieves its full growth, it will comprise:

- Director of market research.
- Assistant director.
- Statistician.
- Cartographer.
- Field force—seniors.
- Field force—juniors.
- Secretary and stenographers.

In this full-grown organization, the director is concerned primarily with:

- Establishment of the market research program.
- Organization.
- Personnel.
- Administration.

The director may or may not personally participate in the actual field work, the collection, preparation, and analysis of data, or in the physical production of the final report. However, the final report and its presentation to management is his sole responsibility, and his reputation depends upon the accuracy and integrity of this document.

Under the director, the statistician or statistician-cartographer should serve as production manager and be responsible for the physical production of the final report, supervising the mechanics of assembling this volume.

Personnel

The director must, first of all, have the proper personal character—integrity, the basic honesty to state facts as he sees them; courage, to present and support his conclusions even though they may be contrary to the views held by his superiors; curiosity, which makes him find out "what makes things tick"; intelligence, the ability to analyze and interpret facts and trends; alertness of perception, the ability, as one DuPonter put it, "to interpret the awkward pauses that occur in a market research interview"; and personality, an interest in people greater than an interest in things and the ability to get along well with others. Also, he must be capable of growth in the business structure.

The director for chemical market research work should be trained as a chemical engineer as the knowledge of processes is essential. Equally important is a strong background in economics and the English language.

On the side of experience, the director should have served several years in actual sales work in order to know what can be sold, and how, and also how to interpret an interview. Some knowledge of manufacturing and research work is also most helpful.

This may sound like a description of Superman, for men like this are hard to find. However, this is, in general, the background of our most successful market research men. It is also interesting to note that the majority of men who started in market research work in the chemical industry twenty years ago have moved up into executive and administrative posts in the industry.

The assistant director should have basically the same background as the director, but may be a little younger. In a company doing work in varied fields, it is sometimes desirable that the assistant director have somewhat different experience from the director's—one man, for example, may have heavy chemical experience and the other, fine organic chemical experience, to provide a diversity of viewpoint.

The statistician should be basically an economist with a flair for figures, but some knowledge of chemistry or chemical engineering is most helpful. This post might possibly be filled by a woman interested in statistical work as a career, or this spot might serve as a training position for a young chemical engineer where he can gain some insight into chemical market research work before going into the field of actual survey duty.

The work of the cartographer can best be handled by a woman with statistical and graphic interests and with some

training in the graphic presentation of facts.

The senior field staff, for manufacturer's-goods work, should be men trained in chemical engineering, willing to travel extensively, and possessed of a strong interest in people. The senior staff man must be able to meet and handle interviews with top-level men in the industries under investigation and report the results factually, distinguishing between what he is told and what he thinks. He should likewise be capable of assuming, if necessary, full responsibility for a project, handling the field work and writing the report. He should have had some experience in sales work.

For consumer-goods market research, the senior staff men need not necessarily be technically trained, but they must be able to meet and get along with all sorts of people and to report interviews factually.

The junior field men, if needed for manufacturer's goods surveys, should be trained as chemical engineers and may be men just out of college. They should be able to develop into seniors rapidly and must be willing to travel extensively and have the persistence to stay with the job.

For consumer-goods work, the junior staff need not be full-time or technically trained people, but they must be capable of following instructions, of getting along with people and of reporting honestly what they learn from an interview. In the case of consumer goods, the type of product under study and the nature of the market will dictate to some extent the kind of people who should be employed.

Administration

Once the staff is properly organized, the director is faced with the questions how shall I run this department and what shall I do first?

Unfortunately, usually his first job is to educate his management as to what chemical market research really is and how it should be conducted. This may sound absurd, but it isn't. Chemical market research is still a new profession, and management's familiarity with it usually ends with acknowledging the need for its services.

Not very long ago, the vice-president-technical-director of a very large chemical corporation handed a bottle containing some white lumpy unknown material and bearing a cryptic label to the market research man with the question, "How much of this can we sell and how much money can we get for it?"

The market research man immediately replied, "Two million seventy thousand and sixty-two tons at a price of forty-nine dollars and thirty-seven cents per ton."

A darned fool answer to a darned fool question!

While both question and answer in this instance were made in mock seriousness, the incident illustrates two points:

1. Management needs to learn what is involved in chemical market research work.
2. The market research director should not start his work until he is given all the facts known to management about the problem or product.

A good chemical market research study is like good whiskey. The longer it ages, the better it will be. A forced, hurried job can lead to faulty conclusions and costly errors. Don't rush this work!

Chemical market research is basically concerned with three operations, namely: collecting data, analyzing and interpreting it, and preparing and presenting the conclusions.

Collecting statistical and field data can usually be completed fairly quickly, but the work of analysis and interpretation should be given ample time.

It is a frailty of the human mind that it can seldom grasp and evaluate all the facts of a problem simultaneously and give them proper weight. It is best therefore for the chemical market research man to collect his facts, study them, and then set the problem aside for a time while work is done on some other project. On returning to the original problem, he often unconsciously takes a new approach, which may change the perspective and the relative weights of the various factors. A period of gestation must be allowed for good chemical market research work. It cannot be turned on and off like a faucet and yield good results.

Chemical market research can best be conducted as a continuing function, and, if the company is interested in a given product or market, the market research work should continue in that field as long as the interest exists, with interim market research reports submitted as the economic picture changes.

It frequently happens that the chemical market research man while working on one project will accidentally uncover facts bearing on another project on the docket, just as a fly fisherman casting for squaretails may unexpectedly hook a rainbow. For this reason, whenever possible, the market research director should be assigned all his problems well in advance and in such a way that work may be done on a number of them concurrently.

Good chemical market research is expensive, and good chemical market research men are not cheap. Travel expense and overhead may equal or even exceed the market research man's salary. Hence, the work must be planned to make maximum use of time and reduce travel expense. If a new product under consideration is estimated to have a minimum cost of $1.00 per pound, there is no sense wasting market research time in exploring that portion of the market requiring a $.50 per pound selling price.

It is imperative in the interest of efficiency and economy that management give the chemical market research director all the facts in its possession about the product—its properties, its manufacturing process, its estimated cost, etc., before market research work is undertaken. By setting the technical and economic limitations thus in advance, much market research time and money can be saved, and the resultant market research report will not be overburdened with irrelevant data.

A market research program should be established on an annual basis. All projects known to be of interest at the beginning of the fiscal year should be listed. Estimates of the time, manpower, and expense required for each project should be made and a timetable and budget established for each item. The timetable should never schedule every available hour of the market research staff's time, as a factor of safety must be provided to allow for "quickie" jobs and new work, which always arises during the course of the year. The cost budget should allow for such unexpected work, or the market research director should request a separate expense appropriation for each new assignment not provided for in his original annual schedule and budget. Sometimes the latter method is preferable, as it tends to keep management from crowding the market research program with "quickie"—and usually worthless—projects to the detriment of the regular work.

Procedure

After the timetable and budget have been established and approved by management, the market research director should then break these down into monthly work schedules for his force, assigning the projects clearly, in writing, and setting deadlines for the completion of each phase of the work.

One-paragraph weekly progress reports on each project should be required from each member of the staff, stating the work done that week, the amount of time and money spent on each project, and the estimated time and expense needed to complete the project.

As the statistical and field data are collected, the director must familiarize himself with it. He should confer frequently with his staff members doing the work and make sure that all pertinent facts are being obtained. This is of considerable importance, as market research work tends to stray away from the original problem and into diverse channels. In these conferences, the market research director should at times deliberately adopt a "show me" attitude to force the staff to prove their facts and statements. He must be a sort of devil's advocate to make sure that no faulty logic has been used in securing the facts or in interpreting them.

The market research director may or may not write the final report, depending upon the size and competence of his staff, but he is personally responsible in the eyes of management for every word it contains, and he should consider it meticulously before it is submitted.

Because of the nature of his duties, the chemical market research director must be completely free to seek and obtain information from all available sources, but under no circumstances is he justified in obtaining information under false pretenses or by violating the ethics of his profession.

The chemical market research director, because of his advisory duties to top management, has access to much confidential company information. He is likewise frequently trusted with confidential information by individuals whom he meets in the course of his work in the field. Such information and data cannot be quoted or used as such, and their sources must never be revealed, but they provide much needed background for the conclusions reached in the market research report.

The chemical market research director is somewhat in the position of the family physician, in that he is an adviser to his "patient"—in this case, his management and the company stockholders. The nature of his work demands that he maintain the highest standards of personal integrity and ethics.

Just as the surgeon stakes his reputation every time he picks up the scalpel to operate, so does the market research director venture his reputation every time he submits a market research report.

This simile is not really too far fetched, as the prime interest of the professional market researcher is in the success of his company. In a way, the chemical market research director is like the Chinese doctor; he is paid to keep his patient—his company—healthy.

Value of Chemical Market Research

One commonly associates chemical market research with the exploration and development of markets for new products. However, this is only one of the many functions the chemical market research department can perform. Among the others may be mentioned:

1. Fact finding for the establishment of sales policies.
2. Analysis of distribution and merchandising methods.
3. Appraisal of sales performance and the analysis of sales territories.
4. Fact finding for the selection of advertising methods and media.
5. Determination of seasonal variations and market trends for the scheduling of production and the control of inventories.
6. Appraisal of projects considered for research to determine whether they have sufficient commercial value to warrant research effort.
7. Determination of the market potentials for new products and the volume and price at which they may be sold.
8. Market fact finding for the guidance of commercial development.
9. General advice to management on trends, projects and special situations.

REGIONAL MARKETS FOR CHEMICALS

RAYMOND H. EWELL

REGIONAL data on the consumption of chemicals are much less readily available than are chemical-consumption data for the United States as a whole. Regions that may be of interest in the consumption of chemicals include (1) major regions of the United States such as New England, the Pacific Coast, etc.; (2) individual states; (3) metropolitan areas, which may cut across state lines; (4) individual cities. Regional data on the consumption of chemicals are useful to chemical companies in many ways, such as locating new plants, district sales offices, and bulk storage facilities or selecting transportation media. There are three basic methods of obtaining regional data on the consumption of chemicals:

1. Direct-survey method: Numerical data are obtained directly from all, or a known proportion of all, consumers of a given chemical in a given region. This procedure will usually involve contacting consumers of the given chemical in a number of different industries.
2. Unit-consumption-factor method: The production of each commodity consuming a given chemical in a given region is multiplied by the appropriate unit-consumption factor.
3. Regional-fraction method: Total United States consumption of a given chemical by each commodity consuming that chemical is multiplied by the fraction of each commodity produced in the given region.

The three methods may be applied, for example, to the consumption of sulfuric acid for the manufacture of gasoline in Texas.

This example concerns only one commodity, namely gasoline. Regardless of which method is being used, the foregoing procedures would then have to be repeated on all commodities and industries consuming sulfuric acid in Texas, in order to obtain an estimation of the total market for sulfuric acid in Texas. This is obviously a large order for sulfuric acid or any other chemical with a diversity of end uses; therefore, all short cuts should be examined carefully

for possible applicability to the problem at hand.

Direct-survey Method. The direct-survey method is generally the preferred method, but it is slow and expensive. Moreover it is necessary to interview all consumers of the chemical in question or know accurately what proportion of the consumers were interviewed. Also, this method may give data which are more accurate (and more expensive) than the immediate purpose requires. In such cases one of the other two methods may be preferred. The direct-survey method is, of course, easier to apply in a familiar field where the company already has a backlog of data than it is in a field new to the company.

Unit-consumption-factor Method. When the required data are available, this method is quick and inexpensive. However, both the regional-production data and the unit-consumption factors are sometimes difficult to obtain with adequate reliability. Whenever possible, the unit-consumption factor used should apply to the particular area in question, although average United States unit-consumption factors can be used in industries with relatively standardized technologies.

Regional-fraction Method. This method is the principal subject of this paper. The regional fractions of any chemical-consuming commodity or industry are preferably based on physical volumes of production, for example, the production of gasoline or glass or tobacco products, in pounds, tons, gallons, or other physical units of quantity. However, data in terms of physical volume are sometimes not available, and in these cases data in terms of dollars can be used to calculate regional fractions of the United States total.

It is impossible, for example, to obtain from publicly available sources any regional data on textile finishing or on leather tanning and finishing in terms of physical volumes of production. However, the Census of Manufactures shows that in 1947 New York did 10.9% of the textile finishing and 13.5% of the leather tanning and finishing in terms of dollar value of production. It may be estimated therefore that in 1947 New York consumed about 11% of the textile dyes and other textile-finishing chemicals and about 13 to 14% of the leather-tanning chemicals. Moreover, in slowly changing industries such as these two, it could be assumed that the percentages of the national business in New York were the same in 1952 as in 1947. At least these estimations would do within the accuracy required for many purposes.

Table 4—Chemicals Used in Industry

Industry or Commodity	Chemicals Consumed
Rayon and related broad-woven goods	Rayon (except high tenacity), acetate fiber, other synthetic fibers, sizes.
South Carolina, North Carolina, and Pennsylvania are outstanding in manufacture of synthetic broad-woven goods.	
Textile finishing	Dyes, dyeing assistants, detergents, bleaches, acetic acid, mordants, resins.
New Jersey occupies the dominant position in textile finishing. Data include cotton and synthetic textiles, but not woolen or worsted.	
Food and kindred products	Packaging films, vitamins, flavors, bleaches, acids, alkalies, emulsifiers, detergents, preservatives, monosodium glutamate, antioxidants, refrigerants, carbon dioxide, caffeine, mold inhibitors, dyes, meat casings, ethyl alcohol, polyalcohols, thickening agents.
Illinois, New York, and California are the outstanding states in this group. "Food and kindred products" includes meat products of all types, dairy products, canned, preserved and frozen foods, grain-mill products, bakery products, sugar, candy, chewing gum, beverages, shortenings, oleomargarine, et al. A good deal of breakdown of these subdivisions by states is available in the Census of Manufactures, 1947.	
Margarine	Hydrogenation catalyst, preservatives, flavors, dyes.
This is a subdivision of "Food and kindred products." Illinois, California, Ohio, Texas and Indiana produce 67% of the nation's margarine. Technology is quite uniform.	
Tobacco products	Polyalcohols, cellophane.
North Carolina and Virginia produce 71% of the nation's tobacco products. Technology of industry is quite uniform among various states.	
Motor vehicles	Antifreezes, radiator cleaners, solvents.
Western states run higher than Eastern states in number of motor vehicles in proportion to population. Consumption of antifreezes is influenced strongly by winter temperatures; few motor vehicles in Florida and less than half in California use antifreeze.	
Crude petroleum	Sodium phosphates and other drilling-mud ingredients, hydrochloric acid, surface-active agents.
Texas and California are the dominant states in crude-oil production. Very little hydrochloric acid is used for oil-well acidizing in California, owing to the absence of limestone in oil formations.	
Gasoline	Ethyl fluid, catalysts (for several processes), sulfuric acid, caustic soda, ammonia, ethanolamines, "sweetening" chemicals, antioxidants, metal deactivators, dyes.

R. H. Ewell

Raymond H. Ewell, manager of the chemical economics service of Stanford Research Institute, joined the organization in 1948 after three years with Shell Chemical Corporation as senior chemical economist. During the war Dr. Ewell was a member of the chemical engineering division of the National Defense Research Committee and for his work received the Medal of Merit. Previously he had been employed as a research chemist with the National Bureau of Standards and as assistant professor of physical chemistry at Purdue University. He received a Ph.D. from Princeton in 1937 and is also a graduate of Purdue and the University of Toledo. Dr. Ewell is co-inventor of the Lecky-Ewell packing for fractionating columns.

Use of the regional-fraction method assumes that the pattern of products and technology in a given industry is the same in all regions. This assumption will be true in many cases, but the regional-fraction method must be applied with caution and judgment and adjusted for any known regional peculiarities of the industry in question.

The other datum required for the application of this method in a particular case is the total United States consumption of a given chemical by a given industry or commodity. Some of the principal sources of such data will be found in a subsequent paper in this series, by R. M. Lawrence and J. H. Sprague.

The principal basis of utility of the regional-fraction method is that it is always easier to obtain total United States consumption data than regional data on a chemical. Obtaining total United States consumption data for a given chemical for a particular end use is simplified in cases where the chemical has only one use. Tetraethyl lead, ammonium sulfate, pentachlorophenol, acetic anhydride, adipic acid, ethylene dibromide, synthetic rubbers, sodium benzoate, and phosphorus are examples of chemicals that have only one use or that go into one product in an overwhelming proportion. However, this simplified situation is the exception rather than the rule.

Major Chemical-consuming Industries

Table 1 shows the consumption of chemicals by the major chemical-consuming industries. Textiles is the big consumer, followed by rubber, surface coatings, agriculture, plastics fabricating, petroleum, etc. Most of these industries have several subclassifications that must be considered individually in making estimates of chemical consumption by the regional-fraction method. For example, the spinning and weaving branch of the textile industry consumes a very different group of chemicals from the finishing branch. Likewise, in the pulp and paper industry, pulp manufacture consumes a very different group of chemicals from paper manufacture. As still another example, the chemicals consumed by the petroleum industry are divided quite distinctly into those consumed in the production of crude petroleum, gasoline, lubricating oil, and greases.

Regional Fractions of Chemical-consuming Industries

Table 2 presents breakdown data by states on four major economic factors and thirty-eight chemical-consuming industries and commodities, representing

Table 4—(*Continued*)

Industry or Commodity	Chemicals Consumed
	Texas and California are the dominant states in gasoline manufacture, also. The pattern of technology is fairly uniform among the principal gasoline-producing states. Some regional variations exist in ethyl fluid usage.
Lubricating oil	Extraction and dewaxing solvents, antioxidants, detergents, corrosion inhibitors, extreme pressure agents, pour-point depressants, viscosity-index improvers.
	Texas and Pennsylvania are the dominant states in lubricating-oil manufacture. Total consumption of lubricating oil additives is 150 to 180 million lb. per year with a value of $60 to $70 million. The use of lubricating-oil additives is reported to be smaller in Pennsylvania than in other states.
Rubber products	Synthetic rubbers, rayon (high tenacity), pigments, rubber-processing chemicals, extenders, lubricants, mold-release materials.
	Ohio occupies the dominant position in the manufacture of rubber products. Tires, tubes, and related materials represent about 65% of the output of the rubber industry in terms of tonnage of rubber consumed, but less than 65% in terms of dollar value of products.
Leather tanning and finishing	Alum, chromium salts, syntans, bleaches, acids, dyes, resins, mold inhibitors.
	Massachusetts occupies the dominant position in leather tanning and finishing.
Glass products	Soda ash, salt cake, borax, boric acid, coloring chemicals.
	Pennsylvania, Ohio, and West Virginia are dominant in the manufacture of glass products. Data include production of glass containers, flat glass, and miscellaneous pressed and blown glass by primary glass producers only.
Metal fabricating	Degreasing solvents, acids, nitriding and carburizing chemicals, welding and cutting gases, electroplating chemicals, corrosion inhibitors, plastics materials.
	Michigan, Ohio, Illinois and New York are the dominant states in this field. Data include all industries fabricating products from metals, including machinery, electrical equipment, transportation equipment, appliances, instruments, etc. The use of chemicals probably varies considerably within this group.
Plastics products	Molding powder, sheets, rods, tubes, plastics in liquid form.
	This industry is quite widely distributed in the more industrialized states. This group comprises the manufacture of products from the primary plastics materials, with the exception of plastic film.
Storage-batteries	Sulfuric acid, lead oxides, plastics.
	Pennsylvania, Ohio, New Jersey, Indiana, and California are the outstanding states in storage-battery manufacture. Technology is quite uniform.
Explosives	Glycerin, ethylene glycol, ammonia, nitric acid, sulfuric acid, sodium nitrate, ammonium nitrate, other nitrogenous explosive materials, sulfur.
	New Jersey and Pennsylvania are dominant in this field. Data include dynamite, permissibles, black blasting powder, other industrial explosives and propellants, fuses, blasting caps, and other blasting accessories. Military and sporting ammunition are not included.
Copper, lead, and zinc ores	Explosives, flotation chemicals.
	None of the more populous states are important in production of these ores. The most important states are Arizona, Utah, Idaho, Missouri, Montana, New Mexico, and Colorado. Data include production and concentration of ores, but not smelting to the metal.
Paint, varnish, and lacquer	Solvents, pigments, resins, latices, nitrocellulose, driers, flatting agents, plasticizers.

over 90% of the consumption of all chemicals. Table 3 illustrates for the ten leading states the percentages obtainable from the figures in Table 2.

The population of a region is an important economic base point, since the population is a fundamental factor in the consumption of many commodities. From a realistic standpoint, however, personal income is a more concrete measure of the consumption potential for many commodities. It determines the volume of business, for instance, of laundries, dry cleaning, and other service industries and hence of the chemicals consumed by these industries. Personal income is an important factor in the consumption of chemicals used directly in the household, such as bleaches, water softeners, pesticides, toilet chemicals, solvents, etc.

The bulk of chemicals is, however, consumed by industry and agriculture and only indirectly by consumers. Therefore, the magnitude and pattern of industry and agriculture in a given region are most directly the determining factors in chemical consumption. Manufacturing production gives a general indication of the relative sizes of the states as industrial consumers of chemicals, although these percentages have little relationship to the consumption of any particular chemical.

As examples of the use of Table 2, the tabulation "Chemicals Used in Industry" (Table 4) shows related industries and the chemicals they consume.

TABLE 1.—CONSUMPTION OF CHEMICALS BY CHEMICAL-CONSUMING INDUSTRIES—1950

	Millions of Dollars
1. Textiles	1,140
2. Rubber	610
3. Paint	575
4. Agriculture	525
5. Plastics-fabricating industry	400
6. Petroleum industry	350
7. Pharmaceutical industry	250
8. Food and kindred products	250
9. Soap and cleansers	110
10. Mining and smelting	100
11. Metal-fabricating industries	95
12. Pulp and paper	90
13. Automobile servicing	80
14. Leather	60
15. Lumber and wood products	50
16. Glass	40
17. Laundry and dry cleaning	35
18. Water treatment	35
19. Photography	35
20. Floor coverings	30
21. Toilet preparations and cosmetics	25
22. Household products	25
23. Ceramics	15
24. About 25 additional chemical-consuming industries (including manufacture of military material)	275
Total consumption of chemicals by United States industries	5,200

Table 4—(Continued)

Industry or Commodity	Chemicals Consumed
	Illinois, New Jersey, and New York are outstanding in manufacture of paint, varnish, and lacquer. All types of paint are made in all the major paint-producing states, although the pattern of the industry may vary somewhat from state to state.
Soap and glycerine	Caustic soda, soda ash, fatty acids, sodium silicate, perfumes.
	Indiana, Ohio, and New Jersey are the dominant states in soap manufacture, although substantial quantities are produced in all industrialized states. Data include manufacture of soap only and do not include synthetic detergents or cleaning preparations.
Cleaning preparations, polishes and waxes	Synthetic detergents, alkyl benzene and other detergent intermediates, soda ash, sodium phosphates, borax, solvents, emulsifiers, alkanolamines, resins.
	New York, New Jersey, and Illinois are the outstanding states in this group. This is a very diverse group including cleaning preparations (other than soap), various types of polishes, waxes, finishes, and dressings. Also included are paint removers and dry-cleaning preparations. Unfortunately, the Census of Manufactures offers no further breakdown by states.
Pharmaceutical preparations	Antibiotics, vitamins, sulfa drugs, aspirin and other analgesics, barbiturates, polyalcohols, ethyl alcohol, thickening agents, germicides, salts, alkalies.
	New York, Indiana, Michigan, New Jersey, and Illinois are outstanding states in this field. These are proprietary and patent preparations.
Toilet preparations	Alcohols, polyalcohols, thickening agents, emulsifiers, alkanolamines, flavors, perfumes, detergents, packaging films.
	New Jersey and New York are dominant in this field, comprising 58% of the industry. This is a very diverse group, including cosmetics, perfumes, dentifrices, hair preparations, deodorants, and many other types of toilet preparations. Unfortunately, the Census of Manufactures offers no further breakdown by states.
Paper and paperboard	Alum, sizes, pigments, dyes, resins, sodium silicate, glycerin.
	New York, Michigan, Ohio, Wisconsin, Louisiana, Pennsylvania, Maine, and New Jersey are the leading states in paper and paperboard manufacture.
Wood preserving	Creosote, pentachlorophenol, zinc chloride, copper naphthenate, chromates, arsenic compounds.
	Texas and Mississippi are the largest states in wood preserving, but the industry is very widespread. No information is available on regional variations in technology.

Agriculture is the fourth largest consumer of chemicals, after textiles, rubber, and paint. Among the chemical products consumed by agriculture are fertilizers, insecticides, fungicides, soil fumigants, weed killers, rodenticides, defoliants, livestock sprays, and livestock feed supplements. Farm income and total crop acreage are shown in Table 2 only as general indicators of the distribution of farming as well as of farm purchasing power. Cotton acreage is of particular interest because cotton is the principal user of both DDT and benzene hexachloride, requiring about 3½ lb. of DDT and 2 lb. of γ-benzene hexachloride per acre per season in the South. The usefulness of the breakdown of fertilizer consumption by states is self-explanatory. Particularly outstanding as fertilizer consumers are North Carolina and the other southern states and also California.

TABLE 3.—PRODUCTION OF CHEMICAL-CONSUMING INDUSTRIES AND COMMODITIES

Percentage Breakdown by States—Selected Examples

Selected states	Population, July 1, 1951	Textile finishing, 1947	Tobacco products, 1949	Gasoline, 1949	Rubber products, 1947	Leather tanning and finishing, 1947	Paint, varnish, and lacquer, 1947	Fertilizer consumption total, 1950-51
California	7.2	0.7	1.3	14.4	6.6	1.2	9.4	7.1
Illinois	5.8	0.7	0.5	7.0	1.6	7.0	14.8	5.7
Massachusetts	3.1	2.5	0.1	0.2	9.6	28.8	2.4	0.5
Michigan	4.3	3.3	0.5	1.3	7.6	3.1	7.3	2.5
New Jersey	3.2	23.3	2.9	2.7	4.8	5.4	13.5	1.3
New York	9.8	10.8	0.7	1.0	3.6	13.5	12.1	3.1
North Carolina	2.7	5.6	48.4	....	0.1	1.8	0.4	9.2
Ohio	5.3	0.8	1.3	4.1	29.1	4.0	10.6	4.6
Pennsylvania	6.9	8.2	4.3	7.9	7.0	12.6	7.3	3.0
Texas	5.2	0.1	....	29.7	0.7	0.2	1.7	3.0

NOTE:—The author will be glad to supply an enlarged version of Table 3, corresponding to Table 2, on request.

TABLE 2.—PRODUCTION OF CHEMICAL CONSUMING INDUSTRIES AND COMMODITIES

	Population, thousand persons, July 1, 1951	Personal income, million dollars, 1951	Manufacturing production, value added by manufacture, million dollars, 1950	Cotton broad-woven goods, million dollars, 1947	Woolen and worsted fabrics, million dollars, 1947	Rayon and related broad-woven goods, million dollars, 1947	Textile finishing, million dollars, 1947	Food and kindred products, value added by manufacture, million dollars, 1947	Margarine, million pounds, 1949-50	Tobacco products, stemmed equivalent, million pounds, 1949	Motor vehicles registered, thousands, 1950	Crude petroleum, million barrels, 1951	Gasoline, million barrels, 1949	Lubricating oil, million barrels, 1947	Lubricating grease, million pounds, 1947	Rubber products, million dollars, 1947	Leather tanning and finishing, million dollars, 1947
Alabama	3,042	2,890	1,034	356.6	.....	.....	11.3	55	4.6	2.4	685.8	1.0	0.5	.....	.....	84.0	.....
Arizona	805	1,151	128	.....	.....	.....	.....	21	.....	.....	270.8	.....	.....	.....	.....	.....	.....
Arkansas	1,910	1,769	321	3.5	.....	.....	.....	41	10.1	0.6	477.3	29.3	6.6	(2)	.....	0.1	.....
California	11,024	21,306	5,121	0.9	1.5	0.2	4.1	852	116.1	13.7	4,620.1	354.5	134.9	5.97	119.2	177.6	12.8
Colorado	1,376	2,158	341	.....	0.3	.....	.....	93	.....	.....	564.2	27.2	3.4	.....	.....	46.6	0.1
Connecticut	2,038	4,071	2,123	38.0	77.1	44.8	25.9	49	.....	0.5	715.9	.....	.....	(3)	(4)	96.2	4.5
Delaware	329	683	288	.....	1.8	.....	8.3	23	.....	1.1	108.3	.....	.....	.....	.....	8.8	37.5
Dist. of Col.	811	2,291	114	.....	.....	.....	.....	27	.....	.....	195.0	.....	.....	.....	.....	.....	.....
Florida	2,961	3,801	440	.....	.....	.....	.....	92	.....	18.8	984.8	0.6	.....	.....	.....	0.2	0.1
Georgia	3,485	3,844	1,227	642.6	21.4	25.8	10.2	133	32.4	3.5	897.5	.....	0.5	.....	.....	2.2	1.1
Idaho	590	800	119	.....	.....	.....	.....	44	.....	.....	272.4	.....	0.6	.....	.....	.....	.....
Illinois	8,820	17,001	7,930	2.3	3.9	.....	3.9	1,010	184.0	4.7	2,651.0	58.2	65.6	3.36	(4)	43.9	74.5
Indiana	4,036	6,655	3,833	4.9	4.2	.....	0.2	291	86.7	1.6	1,434.9	10.6	58.3	1.98	80.6	134.4	7.0
Iowa	2,625	4,019	926	.....	1.9	.....	.....	229	.....	.....	1,072.3	.....	.....	.....	.....	29.6	.....
Kansas	1,950	2,847	614	.....	.....	.....	.....	152	49.2	.....	853.5	115.2	32.7	.....	.....	14.9	.....
Kentucky	2,922	3,115	958	5.7	.....	.....	0.7	289	.....	114.5	783.7	11.6	12.3	.....	.....	0.4	4.4
Louisiana	2,757	3,128	916	2.9	.....	.....	.....	139	2.7	1.2	706.7	231.8	80.2	3.57	71.8	.....	.....
Maine	892	1,182	454	102.3	104.7	18.2	.....	42	.....	.....	276.4	.....	.....	.....	.....	0.9	7.7
Maryland	2,441	3,875	1,455	12.4	4.7	0.4	6.4	189	35.4	0.3	684.7	.....	5.2	.....	.....	74.4	2.1
Massachusetts	4,732	8,223	3,660	209.0	426.2	104.0	60.7	227	.....	0.9	1,280.3	.....	1.9	(3)	(4)	258.0	303.0
Michigan	6,545	11,352	7,392	0.2	6.5	.....	0.2	285	26.0	5.2	2,432.7	13.9	12.0	(2)	32.2(5)	203.8	33.4
Minnesota	2,994	4,414	1,200	.....	5.3	.....	0.2	279	.....	.....	1,168.9	.....	0.9	.....	.....	6.2	6.7
Mississippi	2,193	1,689	281	26.7	.....	.....	.....	34	.....	.....	484.4	37.0	1.4	.....	.....	19.0	.....
Missouri	4,043	6,141	2,024	.....	1.0	.....	1.3	332	18.9	14.6	1,261.4	.....	6.1	.....	.....	11.1	3.8
Montana	589	1,026	108	.....	.....	.....	.....	26	.....	.....	264.9	8.9	5.4	.....	.....	.....	.....
Nebraska	1,348	2,035	271	.....	.....	.....	.....	156	9.8	.....	569.5	2.4	0.6	.....	.....	5.2	0.2
Nevada	171	347	29	.....	.....	.....	.....	3	.....	.....	77.1	.....	.....	.....	.....	.....	.....
New Hampshire	534	747	354	44.7	57.9	29.6	2.6	9	.....	0.8	172.3	.....	.....	.....	.....	2.8	17.5
New Jersey	4,974	8,813	4,867	31.5	97.2	46.5	130.8	355	69.7	30.5	1,579.2	.....	35.1	8.40	89.3	130.1	58.1
New Mexico	704	916	103	.....	.....	.....	.....	8	.....	.....	237.7	53.0	2.4	.....	.....	.....	.....
New York	15,026	30,555	10,506	32.7	91.9	40.8	60.6	977	.....	7.6	3,735.1	4.3	9.6	1.88(3)	(4)	97.6	144.3
North Carolina	4,135	4,350	1,858	632.8	50.9	177.7	31.4	78	.....	502.0	1,056.3	.....	.....	.....	.....	4.0	19.4
North Dakota	605	849	86	.....	.....	.....	.....	22	.....	.....	276.0	.....	.....	.....	.....	.....	.....
Ohio	8,063	14,509	7,967	1.3	41.6	.....	4.3	413	103.3	13.7	2,795.1	3.1	38.9	1.43	(4)	786.6	43.1
Oklahoma	2,266	2,677	344	2.4	.....	.....	.....	76	.....	.....	831.4	187.8	45.7	2.55	(4)	20.1	.....
Oregon	1,558	2,572	807	.....	8.8	.....	.....	108	.....	.....	689.4	.....	.....	.....	.....	1.1	0.2
Pennsylvania	10,559	17,552	8,124	54.6	107.9	142.4	45.8	586	.....	44.8	3,009.8	11.2	74.6	11.41	179.9	188.5	134.9
Rhode Island	793	1,343	615	44.8	146.7	58.1	64.7	23	.....	.....	250.9	.....	1.0	(3)	(4)	44.8	0.3
South Carolina	2,125	2,131	855	795.6	13.4	220.9	63.1	34	15.1	2.4	578.8	.....	0.6	.....	.....	0.1	.....
South Dakota	647	989	63	.....	.....	.....	.....	35	.....	.....	290.1	.....	.....	.....	.....	.....	.....
Tennessee	3,318	3,530	1,172	56.7	10.8	12.9	17.8	132	19.1	5.9	858.1	.....	0.6	.....	.....	100.3	6.7
Texas	7,991	11,285	2,269	53.5	0.7	.....	0.3	338	92.6	0.3	2,968.1	1,010.1	279.2	13.17	270.6	18.0	2.4
Utah	709	1,008	178	.....	1.3	.....	.....	43	.....	.....	247.3	1.4	6.7	.....	.....	.....	.....
Vermont	378	491	206	2.9	32.0	.....	.....	15	.....	.....	120.6	.....	.....	.....	.....	8.2	0.3
Virginia	3,385	4,099	1,326	133.0	14.7	79.1	8.8	88	.....	234.8	917.7	.....	.....	.....	.....	5.8	14.7
Washington	2,425	4,257	1,113	.....	2.4	.....	.....	149	.....	.....	924.2	.....	0.7	.....	.....	0.4	0.1
West Virginia	1,995	2,343	882	.....	9.7	.....	2.3	31	.....	9.8	482.3	2.7	2.4	.....	.....	0.6	22.8
Wisconsin	3,475	5,610	2,687	0.4	8.5	.....	0.3	383	.....	0.4	1,201.2	.....	1.0	(2)	(5)	72.9	106.4
Wyoming	295	508	38	.....	.....	.....	.....	8	.....	.....	145.4	67.9	11.2	.....	.....	.....	.....
U. S. Total	153,383	242,947	89,676	3,294.6	1,355.2	1,002.9	560.3	9,025	875.7	1,036.4	49,161.7	2,244.2	939.1	58.28	1,198.3	2,699.2	1,070.1

All data are production or value of products shipped unless otherwise stated.
Numbers in parentheses ( ) refer to notes at end of table.

TABLE 2 —(*Continued*)

	Glass products, million dollars, 1947	Metal fabricating, million dollars, 1947	Plastics products, n.e.c., million dollars, 1947	Furniture, million dollars, 1947	Storage batteries, million dollars, 1947	Explosives, million dollars, 1947	Copper, lead, and zinc ores, thousand tons, 1949	Coal, (16), million tons, 1950	Paint, varnish and lacquer, million dollars, 1947	Printing ink, million dollars, 1947	Soap and glycerine, million dollars, 1947	Cleaning preparations, polishes, and waxes, million dollars, 1947	Pharmaceutical preparations, million dollars, 1947	Toilet preparations, million dollars, 1947	Wood pulp, sulfite, thousand tons, 1950	Wood pulp, sulfate, thousand tons, 1950	Paper and paperboard, thousand tons, 1947
Alabama	.....	100	....	6.6	0.9	....	.....	14.4	3.8	....	0.2	0.2	0.3	0.3	.....	476	375
Arizona	.....	6	....	0.8	....	3.1	463.2	....	0.6	....	0.1	....	0.1	.....	.....	.....	8
Arkansas	5.9	10	....	22.5	....	....	.....	1.2	1.3	....	.....	....	0.3	.....	.....	(9)	190
California	40.0	1,267	24.4	117.4	27.5	9.8	18.2	....	117.4	10.8	71.9	15.3	23.6	17.4	.....	(13)	496
Colorado	3.6	41	0.4	3.6	....	0.8	77.0	4.3	4.5	0.3	.....	1.4	0.3	.....	.....	.....	9
Connecticut	.....	992	32.4	15.4	0.2	4.0	.....	....	7.7	0.5	1.0	1.7	19.5	13.6	.....	.....	363
Delaware	.....	26	4.8	.....	....	....	.....	....	7.2	....	.....	2.9	.....	.....	.....	.....	50
Dist. of Col.	.....	4	0.2	0.4	0.8	....	.....	....	0.3	0.2	.....	....	0.6	0.6	.....	.....	7
Florida	0.6	41	0.2	8.3	2.1	....	.....	....	2.6	....	.....	0.2	1.1	0.3	(6)	1,093	633
Georgia	.....	72	0.2	21.7	....	....	.....	....	7.2	0.7	8.2	2.8	1.4	0.3	.....	1,025	506
Idaho	.....	1	....	0.1	....	....	157.3	....	.....	....	.....	....	.....	.....	.....	.....	.....
Illinois	94.6	2,789	56.1	195.7	15.4	9.2	22.0	56.3	184.6	29.8	105.1	29.9	99.3	35.4	.....	.....	776
Indiana	73.7	1,302	16.4	161.8	30.5	....	.....	20.0	32.2	0.1	154.1	11.1	147.6	3.6	.....	.....	392
Iowa	.....	202	0.2	16.4	2.8	....	.....	1.9	15.3	0.2	7.0	1.8	5.5	1.8	.....	.....	56
Kansas	.....	107	0.2	4.2	4.9	7.2	39.2	2.1	1.0	....	72.2	0.2	0.8	.....	.....	.....	47
Kentucky	0.7	133	0.7	45.3	1.4	8.9	1.1	78.5	32.0	....	0.2	0.7	0.3	0.1	.....	.....	.....
Louisiana	8.1	57	....	7.5	0.8	....	.....	....	5.9	0.4	0.2	0.4	0.6	0.1	.....	1,173	1,343
Maine	.....	40	0.4	2.1	....	....	.....	....	0.7	....	.....	0.2	0.1	.....	409	(10)	1,256
Maryland	11.9	317	10.1	11.3	....	....	.....	0.6	16.1	0.9	78.3	5.6	11.0	0.3	.....	(11)	259
Massachusetts	3.1	1,008	56.5	69.7	6.2	....	.....	....	29.5	3.5	88.5	25.0	11.1	5.6	(7)	.....	742
Michigan	6.7	3,352	11.2	137.6	1.4	....	19.5	....	91.7	4.0	3.1	6.8	126.0	1.8	(8)	(12)	1,536
Minnesota	9.1	284	54.0	13.4	8.5	....	.....	....	14.3	0.5	1.4	1.8	2.7	28.3	(8)	(12)	710
Mississippi	5.9	38	....	6.5	....	....	.....	....	0.3	....	.....	....	0.3	0.6	.....	(9)	462
Missouri	10.4	492	3.2	37.1	3.8	8.0	137.1	3.0	44.8	2.7	21.6	7.0	49.0	9.8	.....	.....	48
Montana	.....	1	....	0.6	....	....	128.8	2.5	.....	....	.....	....	.....	.....	.....	.....	.....
Nebraska	.....	39	1.6	5.6	1.5	....	.....	....	0.3	....	0.1	1.9	4.8	0.2	.....	.....	.....
Nevada	.....	.....	....	.....	....	....	69.1	....	.....	....	.....	....	.....	.....	.....	.....	.....
New Hampshire	.....	44	0.6	8.9	....	....	.....	....	0.2	....	.....	0.6	0.7	0.1	(7)	(10)	224
New Jersey	64.2	1,242	48.5	35.5	35.4	40.5	51.0	....	168.3	12.5	125.7	32.2	111.8	121.4	.....	.....	1,105
New Mexico	.....	1	....	0.7	....	0.4	89.4	0.7	.....	....	.....	....	.....	.....	.....	.....	.....
New York	52.0	2,422	62.9	274.7	16.3	5.6	39.3	....	151.0	25.1	102.9	51.6	173.3	93.9	205	(10)	1,850
North Carolina	.....	59	0.3	182.3	0.6	....	.....	....	5.4	....	0.2	0.8	11.2	0.1	.....	519	389
North Dakota	.....	1	....	.....	0.7	....	.....	3.3	0.1	....	.....	....	.....	.....	.....	.....	.....
Ohio	130.0	2,882	52.7	176.0	36.0	2.1	.....	37.8	132.9	7.4	145.3	16.1	22.8	23.8	.....	.....	1,463
Oklahoma	25.7	66	0.1	4.4	1.5	0.6	63.9	2.7	3.3	....	.....	....	0.1	0.3	.....	.....	.....
Oregon	....	60	0.1	24.1	3.3	....	.....	....	6.5	0.1	1.8	0.2	0.1	0.1	305(6)	(13)	372
Pennsylvania	200.3	2,115	40.0	113.5	48.6	25.6		(15) 149.9	91.5	13.6	49.9	11.6	80.9	3.9	112	(10)	1,293
Rhode Island	1.9	140	3.2	4.2	0.1	....	.....	....	5.0	....	5.9	1.5	0.7	0.2	.....	.....	10
South Carolina	2.0	13	0.3	12.9	9.9	....	.....	....	0.8	....	.....	0.2	0.3	.....	.....	(11)	594
South Dakota	.....	3	....	.....	....	....	.....	....	.....	....	.....	.....	0.1	0.2	.....	.....	.....
Tennessee	6.7	112	0.2	40.9	6.2	....	43.5	(15) 5.1	5.7	0.2	0.5	0.6	20.9	2.1	.....	.....	211
Texas	10.3	305	2.8	28.9	16.1	0.2	0.2	....	20.7	0.9	31.9	2.9	3.1	1.1	.....	(9)	255
Utah	.....	7	0.1	2.3	....	3.5	291.0	6.7	0.6	....	0.1	....	0.1	0.3	.....	.....	.....
Vermont	.....	37	3.7	7.7	....	....		(15)	0.2	....	.....	1.8	1.1	.....	.....	.....	103
Virginia	.....	108	0.3	95.8	....	....	16.5	17.7	7.7	0.7	.....	0.2	2.4	2.2	.....	549	746
Washington	6.1	124	0.3	22.9	0.7	4.7	22.4	0.9	4.7	...	1.9	0.2	0.3	0.3	1,047	541	817
West Virginia	126.6	95	0.1	4.1	0.4	....	.....	144.1	.....	....	.....	1.0	1.1	0.2	.....	.....	26
Wisconsin	.....	1,005	13.4	56.7	11.7	1.9	6.2	....	23.0	1.6	6.5	22.5	4.7	1.4	489	173	1,392
Wyoming	.....	1	....	.....	1.1	....	.....	6.3	0.1	....	.....	....	.....	.....	.....	.....	.....
U. S. Total	900.1	23,573	503.0	2,007.9	297.7	136.4	1,755.9	560.4	1,248.8	115.7	1,085.8	261.6	941.7	371.9	2,851	7,496	21,114

All data are production or value of products shipped unless otherwise stated.
Numbers in parentheses ( ) refer to notes at end of table.

TABLE 2.—*(Continued)*

	Plywood (17), softwood, million sq.ft., ⅜-in. basis, 1951	Wood preserving, million cu.ft., 1951	Farm income, million dollars, 1951	Total crop acreage, thousand acres, 1951	Cotton acreage, thousand acres, 1951	Fertilizer Consumption			
						Total, thousand tons, 1950-51	Nitrogen, thousand tons, 1950-51	Phosphoric oxide, thousand tons, 1950-51	Potash, thousand tons, 1950-51
Alabama		11.0	421.4	4,979	1,460	1,305.1	69.1	121.7	67.0
Arizona		(14)	354.2	1,114	545	104.2	22.3	11.2	0.6
Arkansas		9.3	571.0	5,518	2,025	283.3	40.6	32.8	34.0
California	364.6	14.5	2,574.4	6,886	1,320	1,448.6	142.0	66.3	18.2
Colorado		5.1	545.7	6,301	.....	50.8	6.8	11.0	1.2
Connecticut		(14)	166.7	327	.....	89.0	4.6	7.2	6.8
Delaware		(14)	118.1	429	.....	67.3	2.7	7.2	7.6
Dist. of Col.		.....	.....	.....	.....	2.2	0.1	0.2	0.1
Florida		12.4	478.7	1,158	62	1,002.4	53.5	68.8	77.9
Georgia		14.8	650.8	6,414	1,410	1,312.0	67.0	109.1	81.9
Idaho		3.9	385.3	3,552	.....	47.3	3.3	9.2	0.3
Illinois		17.2	2,628.2	20,760	.....	1,176.9	27.3	84.0	77.2
Indiana		4.6	1,175.6	11,003	.....	934.6	37.1	111.6	106.1
Iowa		(14)	2,410.9	21,861	.....	386.1	20.3	59.7	20.0
Kansas		.....	1,044.0	19,632	.....	185.7	14.8	39.2	2.4
Kentucky		9.1	640.0	4,982	.....	566.2	23.6	66.7	34.8
Louisiana		15.3	392.6	2,975	935	324.8	38.3	28.2	16.6
Maine		(14)	176.3	978	.....	164.9	9.6	18.4	19.3
Maryland		2.9	277.3	1,576	.....	275.8	9.7	33.1	20.3
Massachusetts		.....	206.5	391	.....	95.6	4.6	10.1	8.4
Michigan		(14)	781.0	7,836	.....	505.6	15.7	68.8	53.1
Minnesota		10.8	1,384.7	19,476	.....	201.0	7.3	41.4	21.7
Mississippi		18.6	564.7	5,512	2,340	792.7	96.4	55.5	35.1
Missouri		7.2	1,223.7	12,326	490	637.3	29.5	68.8	38.1
Montana		6.2	454.4	9,185	.....	20.8	2.0	5.3	.....
Nebraska		.....	1,106.1	19,537	.....	67.9	11.8	8.3	0.3
Nevada		.....	59.9	442	.....	1.1	.....	0.2	.....
New Hampshire		(14)	74.6	333	.....	26.5	0.8	4.0	2.3
New Jersey		4.4	351.1	798	.....	257.7	13.0	27.1	23.2
New Mexico		(14)	234.0	1,398	315	21.7	2.4	5.2	0.1
New York		(14)	964.5	5,694	.....	626.9	26.2	83.4	37.0
North Carolina		3.3	940.6	6,208	690	1,899.2	101.3	163.1	127.4
North Dakota		.....	656.8	21,662	.....	14.2	0.6	4.4	1.0
Ohio		12.7	1,071.5	10,611	.....	951.7	31.1	119.4	98.8
Oklahoma		4.5	628.0	10,474	1,475	146.2	5.3	18.8	4.3
Oregon	1,202.1	13.3	410.3	2,880	.....	124.5	17.3	13.5	3.1
Pennsylvania		4.2	873.1	5,662	.....	625.4	21.9	82.5	44.4
Rhode Island		(14)	24.9	41	.....	17.7	0.9	1.8	1.4
South Carolina		12.8	387.9	3,998	1,070	959.5	60.6	81.7	59.0
South Dakota		(14)	675.3	17,801	.....	8.7	0.6	1.7	0.1
Tennessee		5.3	494.6	5,222	765	548.3	28.1	60.6	37.5
Texas		29.2	2,173.1	24,695	11,750	609.6	38.2	88.9	17.5
Utah		(14)	196.3	1,216	.....	28.6	4.0	3.5	0.2
Vermont		.....	127.7	1,027	.....	63.0	1.4	10.5	4.8
Virginia		8.1	523.5	3,442	19	831.4	36.8	91.1	59.6
Washington	1,428.1	14.7	568.2	4,192	.....	86.2	11.9	9.4	4.0
West Virginia		(14)	134.2	1,184	.....	101.0	2.4	15.9	5.6
Wisconsin		(14)	1,194.0	10,188	.....	410.4	12.0	53.0	58.7
Wyoming		(14)	181.0	1,942	.....	6.3	0.2	2.0	.....
U. S. Total	2,994.8	299.6	33,076.7	335,817	26,687	20,507.9	1,171.4	2,086.0	1,337.3

NOTES

(1) Leaders (. . .) indicate quantity is zero or so small as to be less than ½ the smallest unit used in the column or less than 0.05% of the U. S. total.
(2) Arkansas, Michigan, and Wisconsin combined produced 4.51 million barrels.
(3) Includes small amounts produced in Massachusetts, Connecticut, and Rhode Island.
(4) Connecticut, Illinois, Massachusetts, New York, Ohio, Oklahoma, and Rhode Island combined produced 354.7 million pounds.
(5) Includes a small amount produced in Wisconsin.
(6) Includes production of one company in Florida.
(7) New Hampshire and Massachusetts combined produced 141,000 tons.
(8) Michigan and Minnesota combined produced 143,000 tons.
(9) Texas, Arkansas, and Mississippi combined produced 676,000 tons.
(10) Maine, New Hampshire, New York, and Pennsylvania combined produced 186,000 tons.
(11) South Carolina and Maryland combined produced 791,000 tons.
(12) Michigan and Minnesota combined produced 133,000 tons.
(13) Oregon and California combined produced 162,000 tons.
(14) Arizona, Connecticut, Delaware, Iowa, Maine, Michigan, New Hampshire, New Mexico, New York, Rhode Island, South Dakota, Utah, West Virginia, Wisconsin, and Wyoming combined preserved 24.3 million cu.ft.
(15) Ore production in Tennessee includes small amounts of copper ores produced in Pennsylvania and Vermont.
(16) Coal includes bituminous, lignite, and anthracite.
(17) California, Oregon, and Washington produce about 99% of the softwood plywood in the U. S., the other 1% being produced in hardwood plywood mills in a number of Eastern states.

Sources of Data

All data for the year 1947 are from Census of Manufactures (1947), Bureau of the Census.

Other data from following sources:

Population: Current Population Reports, Series P-25, No. 62, Bureau of the Census (August 24, 1952).
Personal income: Survey of Current Business, Department of Commerce (August 1952).
Manufacturing production: Annual Survey of Manufactures: 1949 and 1950, Bureau of the Census (1952).
Margarine: Annual Report of the Commissioner of Internal Revenue for Year Ended June 30, 1950, Bureau of Internal Revenue.
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Motor vehicles: Highway Statistics—1950, Bureau of Public Roads (1952).
Crude petroleum: Monthly Petroleum Statement No. 346, Bureau of Mines.
Gasoline: Minerals Yearbook, 1949 Bureau of Mines (1951).
Copper, lead, and zinc ores: Minerals Yearbook 1949, Bureau of Mines (1951).
Coal: Minerals Yearbook (1950 preprint), Bureau of Mines (1952).
Wood pulp, sulfite and sulfate: Wood Pulp Statistics, United States Pulp Producers Association (August 1951).
Plywood, softwood: Facts for Industry M13B-01, Bureau of the Census (July 14, 1952).
Wood preserving: Letter from Mr. Henry B. Steer, U. S. Forest Service (May 5, 1952). Data compiled by U. S. Forest Service in cooperation with American Wood-Preservers Association.
Farm income: The Farm Income Situation, FIS-133, Bureau of Agricultural Economics (February 22, 1952).
Total crop acreage: Crop Production, Crop Reporting Board, Bureau of Agricultural Economics (1951), Annual Survey issue.
Cotton acreage: The Cotton Situation, CS-140, Bureau of Agricultural Economics (June 6, 1952).
Fertilizer consumption: Commercial Fertilizers, Consumption in the United States, 1950-51, Bureau of Plant Industry, Soils and Agricultural Engineering.

A PLEA FOR SIMPLICITY

HOWARD M. MATHIS

C. F. Braun & Company, Alhambra, California

NOT long ago the author heard a story about a college student. It seems that some friends dared the student to put a certain paragraph into a technical report he was writing. The paragraph went something like this:

"The evolution of the reactionary retrograde dispersion, which culminated in the inclusive phenomenon of synthetic emissivity, which is usually demonstrative of optimum paradoxes, except for biannual regression of calisthenics in the case of heterogeneous phase sequences . . ." and so on and on for half a page.

After going through with the dare the student finished his paper, handed in the report, and waited to see what would happen. But not a single thing happened. The professor graded the paper and handed it back to the student. He hadn't seen anything wrong.

Whether or not the story is true doesn't matter. It *could* have been true, and it clearly illustrates a point. Our technical writings are often almost totally incomprehensible. A paragraph of pure double-talk could easily pass unnoticed. We seem to glory in big words, long involved sentences, ambiguous constructions, and the like.

Do things have to be this way? Is there something about technical reports that demands a pompous style of writing? Must we make things difficult for the reader?

Granted, certain technical explanations must be expressed in technical terms. Such terms require a background of education and vocabulary in the reader. They could not be explained to anyone who did not have this background. They cannot be simplified. However, there is a part of our writings that *can* be simplified, *i.e.*, the part that could be understood more easily if it were expressed in straightforward thoughts—in short sentences and in ordinary words.

Does anyone still think that involved writing is a mark of erudition? If he does, let him look at the great literature, the enduring literature. What will he find? Clarity, simplicity, brevity, unity. The greatest thinkers express their thoughts in the simplest ways.

A few excerpts taken at random from a recent issue of a technical paper will serve as good examples of the need for simplicity.

EDITOR'S NOTE

One reader of technical journals has a serious gripe—authors are not clear in their meaning and simple in their language. When he makes claims that enduring literature is always simple, one is reminded of the chapter on jargon in Quiller-Couch's "On the Art of Writing," wherein he cites the simplicity of: "Render unto Caesar the things that are Caesar's" as against such wordiness as: "Render unto Caesar the things that appertain to that potentate." This article elaborates on the need for simple and clear language in writing technical reports.

These excerpts suffer somewhat because they have been lifted from their context. But each is a complete sentence, presumably written to express a thought. In the first one the author is talking about knowing how certain materials respond to corrosive agents.

Assuming that such knowledge is available or can be predicted with a fair degree of accuracy, the potentialities of operating equipment to yield optimum conditions for best corrosion resistance can be reviewed.

As technical writing goes, this is not bad. You can understand it after two or three readings. But by breaking down this long sentence into two short ones, leaving out the words, "potentialities" and "optimum," we come out thus:

Suppose we do know this, or can predict it fairly well. Then we can decide how to operate the equipment to give us the best corrosion resistance.

Note the simplicity. We have expressed the same thought, using the least number of technical terms. We have changed from passive to active voice and have brought life into our writing.

In the second illustration, the author is stating that sometimes an oxide-film forms on a metal, and that this film resists corrosion better than the metal itself. Then he goes on:

In such cases the presence of oxygen or an oxidizing agent tends to maintain this film, which might otherwise be destroyed, and can be beneficial in maintaining good corrosion resistance.

Here, the construction is so involved that the meaning is not clear. What "can be beneficial?" The oxygen? The film? Or the destruction of the film? We think we know the answer, but we're not sure. Wouldn't it be better to remove this doubt?

The film might be destroyed without oxygen or an oxidizing agent. With them, the film stays on. Thus oxygen helps the corrosion resistance.

Certainly this revision is easier to read and clearer, too. Besides, a complicated thirty-word sentence becomes three short, simple, statements of twenty-three words.

One more example: This time the author is discussing the poisoning of catalysts in fluid catalytic-cracking units. He uses a term called "catalyst selectivity." And he defines this term early in the article. But then he goes on:

Although it is possible for the refiner to control the selectivity deterioration by continually discarding a fraction of the catalyst in the unit and replacing it with fresh material of good selectivity, this expedient increases operating costs because of the additional catalyst consumption.

If this sentence is read aloud the reader will be out of breath by the time he reaches the end. This is a fine example of trying to do too much in one sentence. The author has three thoughts here and each one should have its own sentence.

The refiner has a way to keep the selectivity up. He can keep adding fresh catalyst and throwing away part of the old. But this costs him money because he uses more catalyst.

Once more, fewer words with no sacrifice of meaning spell a gain in simplicity. And, again, interest is added by making expressions real and personal.

These rewrites are not necessarily the best that could be done. But they show that technical writing need not be complicated and abstruse. Usually, the simplest way to say a thing is the best way. And this often turns out in the end to be the easiest way.

No hard-and-fast rules exist for writing simply, but here are a few guideposts:

Try to write as you would speak.

Avoid long, involved sentences.

Question every word you use—is it the simplest one that will do the job?

Make your construction clear—if there is any possible doubt as to your meaning, better rewrite.

Don't succumb to the lure of flowery language.

Simple writing cannot be learned overnight. Most of us are rooted in the old traditions. You will have to work hard for a while on everything you write. But in time you will be able to express your thoughts easily, simply, and understandably.

PLASTICS EQUIPMENT REFERENCE SHEET

RAYMOND B. SEYMOUR and ROBERT H. STEINER

The Atlas Mineral Products Co., Mertztown, Pa.

HIGH IMPACT STYRENE COPOLYMER. These materials are essentially a blend of styrene-acrylonitrile and butadiene - acrylonitrile copolymers. This unfilled rigid plastic material is available from domestic sources as sheets in thicknesses up to 1 in. and as pipe in sizes up to 2 in. IPS. Bolts, nuts, elbows, tees, couplings and flanges are available commercially to fit ½-, ¾-, 1-, 1½- and 2-in. threaded pipe.

APPLICATION AND REMARKS: Sheet may be heat-formed and cemented but cannot be hot-gas-welded. Rods and tubing can be extruded readily and special fittings can be injection-molded. Use of forming and cementing techniques makes possible the fabrication of chemical resistant structures such as ducts, hoods, plenum chambers, stacks, splash covers and tanks.

CHEMICAL COMPOSITION: Usually blends of copolymers of acrylonitrile with styrene and butadiene in which the acrylonitrile is the minor constituent.

MACHINABILITY: Can be formed by use of dies or blowing techniques, cemented, ground, turned, sanded, stamped, drilled and milled. No lubricant is required but a coolant is recommended in many machining operations. High cutting speeds and light cuts are suggested for all turning or routing operations.

TEMPERATURE LIMITATIONS: Not recommended for use above 160° F.

TYPICAL MECHANICAL AND PHYSICAL PROPERTIES:

Tensile strength, lb./sq.in.	4,000
Elongation %	40
Impact Notch, Izod ft.lb./in. @ 70° F.	9
Hardness, Rockwell M	90
Flexural Strength, lb./sq.in.	6,500
Compressive Strength, lb./sq. in.	10,000
Modulus of Elasticity (x 10⁵ lb./sq. in.)	2
Specific Gravity	1.04
Heat Distortion (° F.)	190
Thermal Expansion (in./in. ° F. x 10^{-5}) (70-120° F.)	3.4
Thermal Conductivity, B.t.u./(sec.)(sq.ft.)(° F./in. x 10^{-4}) (70-120° F.)	1.0
Water Absorption %	0.35

CORROSION RESISTANCE

	C	H
ACIDS		
Acetic, 10%	E	E
Acetic, glacial	N	N
Benzene sulfonic	E	E
Benzoic	E	E
Boric	E	E
Butyric	N	N
Chloroacetic	N	N
Chromic, 10%	E	N
Chromic, 50%	F	N
Citric	E	E
Fatty Acids	E	E
Fluosilicic	E	E
Formic, 90%	N	N
Hydrobromic	E	F
Hydrochloric	E	F
Hydrocyanic	E	E
Hydrofluoric	E	F
Hypochlorous	E	F
Lactic	E	E
Maleic	E	N
Nitric, 5%	G	N
Nitric, 20%	F	N
Nitric, 40%	N	N
Oleic	E	E
Oxalic	E	E
Perchloric	E	F
Phosphoric	E	E
Picric	E	E
Stearic	E	E
Sulfuric, 50%	E	N
Sulfuric, 70%	G	N
Sulfuric, 93%	N	N
Oleum	N	N
Mixed Acids 57% H_2SO_4 28% HNO_3	N	N
ALKALIES		
Ammonium hydroxide	E	E
Calcium hydroxide	E	E
Potassium hydroxide	E	E
Sodium hydroxide	E	E

	C	H
ACID SALTS		
Alum or Aluminum sulfate	E	E
Ammonium chloride, nitrate, sulfate	E	E
Copper chloride, nitrate, sulfate	E	E
Ferric chloride, nitrate, sulfate	E	E
Nickel chloride, nitrate, sulfate	E	E
Stannic chloride	E	E
Zinc chloride, sulfate	E	E
ALKALINE SALTS		
Barium sulfide	E	E
Sodium bicarbonate	E	E
Sodium carbonate	E	E
Sodium sulfide	E	E
Trisodium phosphate	E	E
NEUTRAL SALTS		
Calcium chloride, sulfate	E	E
Magnesium chloride, sulfate	E	E
Potassium chloride, sulfate	E	E
Sodium chloride, sulfate	E	E
GASES		
Chlorine, wet	E	N
Chlorine, dry	F	F
Sulfur dioxide, wet	F	E
Sulfur dioxide, dry	E	E
ORGANIC MATERIALS		
Acetone	N	N
Alcohols, methyl, ethyl	E	P
Aniline	N	N
Benzene	N	N
Carbon tetrachloride	N	N
Chloroform	N	N
Ethyl Acetate	N	N

	C	H
Ethylene dichloride	N	N
Formaldehyde, 37%	E	E
Phenol, 5%	G	F
Refinery crudes	E	E
Trichloroethylene	N	N
PAPER MILL APPLICATIONS		
Kraft liquor	E	F
Black liquor	E	F
Green liquor	E	F
White liquor	E	F
Sulfite liquor	E	F
Chlorite bleach	E	P
Alum	E	E
PHOTOGRAPHIC INDUSTRY		
Developers	E	E
General use	E	E
Silver nitrate	E	E
FERTILIZER INDUSTRY		
General use	E	F
STEEL INDUSTRY		
Sulfuric acid pickling	E	E
Hydrochloric acid pickling	E	E
H_2SO_4-HNO_3 pickling	N	N
TEXTILE INDUSTRY		
General use	E	E
FOOD INDUSTRY		
General use	E	E
Breweries	E	E
Dairies	E	E
MISCELLANEOUS INDUSTRIES		
Plating	E	G
Petroleum	E	E
Tanneries	E	E
Oil and Soap	E	E
Water and Sewer	E	E

RATINGS

E—No attack.
G—Appreciably no attack.
F—Some attack but usable in some instances.
P—Attacked—not recommended.
N—Badly attacked.
C—Cold—77° F.
H—Hot—170° F.

No. 15

CLEVELAND

"A Center for Chemical Industry"

George W. Blum

Case Institute of Technology

Cleveland, Ohio

CLEVELAND, the locale of the Forty-fifth annual meeting of A.I. Ch.E. (Dec. 7-10, 1952), is publicized as "The Best Location in the Nation," occupying as it does a strategic geographical situation for the continued growth of industrial enterprise.

Moses Cleveland located a small village on the banks of the Cuyahoga River in 1796, and from this small trading post for the Western Reserve Territory it has grown into the industrial and manufacturing city of Greater Cleveland which parallels the shore line of Lake Erie from Painesville to Lorain. Transportation facilities, so essential to industrial growth, serve Cleveland effectively. Seven railroads, 106 major truck lines, and five major air lines provide dependable service. Cleveland occupies a dominant position in the shipping in-

dustry of the Great Lakes, and as a result vast quantities of iron ore, coal, grain, lumber and other bulk commodities are processed from the Cleveland docks. About 350 lake cargo boats operate in and out of Cleveland, more than three fourths of which are owned by companies whose headquarters are located here. A vast network of intercommunicating, broad "freeways" are under construction; many sections are currently in use, and when all are completed, the city can be traversed rapidly and uninterruptedly in any direction by wide superhighways. When a St. Lawrence ship canal becomes a reality, great benefit will accrue to industries in this area, which will acquire a direct ocean outlet for shipping and such new raw material sources as Labrador. The city now benefits uniquely from the availability of iron ore from the Mesabi, coal from Pennsylvania, West Virginia and southern Ohio and ample limestone in the vicinity. These have resulted in the rapid growth of not only the steel industry itself, but also the related machinery. This rate of growth has been especially marked during the past five years.

Well-populated Strategic Area. More than 200 million dollars have been invested or appropriated for new chemical facilities since V-J Day; half of this amount has been announced since the start of the Korean conflict. This capital investment has taken place because of the area's proximity to raw materials and markets, unlimited fresh water, and adequate, dependable electric power.

The Cleveland-Northeast Ohio area, which extends for about 100 miles along the south shore of Lake Erie from the Ohio-Pennsylvania border has about eighty-five million people (more than 55% of the nation's population) located within a 500-mile radius. It is located midway between New York and Chicago, the two largest marketing areas in the country. Within this 500-mile radius there is produced 75% of all the manufactured goods of the nation, measured in terms of dollar value.

A Paint-pigment Center. The chemical industry in the area was born during the Civil War with the advent of petroleum refining by John D. Rockefeller. In 1865, Eugene Grasselli started a sulfuric acid plant to supply the oil and steel industries. In the seventies, Cleveland began to assume its leadership in the paint field with the founding of Sherwin-Williams in 1870 and the Glidden Co. in 1875. With the many other leading companies manufacturing paints, varnishes and other protective-coating materials, Cleveland has frequently and aptly been referred to as the "Paint Capital of the World." These include the Arco and Ferbert Schorndorfer divisions of American Marietta, the Ault and Wiborg division of Interchemical, the Forbes finishes division of Pittsburgh Plate Glass, the Lacquer Products Co., the Patterson Sargent Co., and dozens of smaller, independent companies which, in general, manufacture specialty finishes.

The Ferro Corp. is the world's largest producer of porcelain enamel frits and also produces colors for ceramics, glass, and plastics. There is a subsidiary, Ferro Chemical in Bedford, which produces metallic soaps for the paint and varnish industry.

Plastics-fabricating Establishments. A vast range of industrial enterprise has developed in the plastics and polymer field. Naugatuck chemical division of the U. S. Rubber Co. has extensive manufacturing capacity for vinyl chloride resins, located in Painesville, adjacent to the plant of Diamond Alkali Co., from whom it receives its anhydrous HCl. The Goodrich Chemical Co. is constantly augmenting the scope of its plastics and chemical facilities in Avon Lake, Ohio, since their construction in 1947. The Ohio Rubber Co. fabricates a wide variety of rubber and rubber base products of specialty nature. The Harshaw Chemical Co., the Ferro Corp. and the Diamond Alkali Co. have developed many new opacifiers, fillers, pigments, driers, and stabilizers for the rapidly changing vinyl fabrication applications. Compression, injection, extrusion, plunger and plastisol molding facilities are readily available for custom parts. These companies utilize a wide variety of resins, including the phenolics and ureas, polyester Fiberglas compounds, polyethylene, polystyrene and the fluorinated polymers. Structural parts manufacturers include well-known firms in these fields, such as Heil Process Equipment Co. for tank and equipment lining in polyester, polyethylene, furan and Neoprene and plastic ventilation ducts and hoods; the American Agile Co. and the Carter Products Co. in plastic pipe, and fittings, as well as plastic tanks auxiliaries and containers.

Materials, Fresh Water in Abundance. The raw material basis for this chemical growth consists of such readily available materials as salt, brine, dolomite, limestone, silica, oil, and coal. A vast stratum of salt, 150,000 to 200,000 tons/acre, lies at a depth of about 1500 ft., and is easily brined out at a low cost. There are natural brines, rich in magnesium and bromine, at levels above and below the salt stratum.

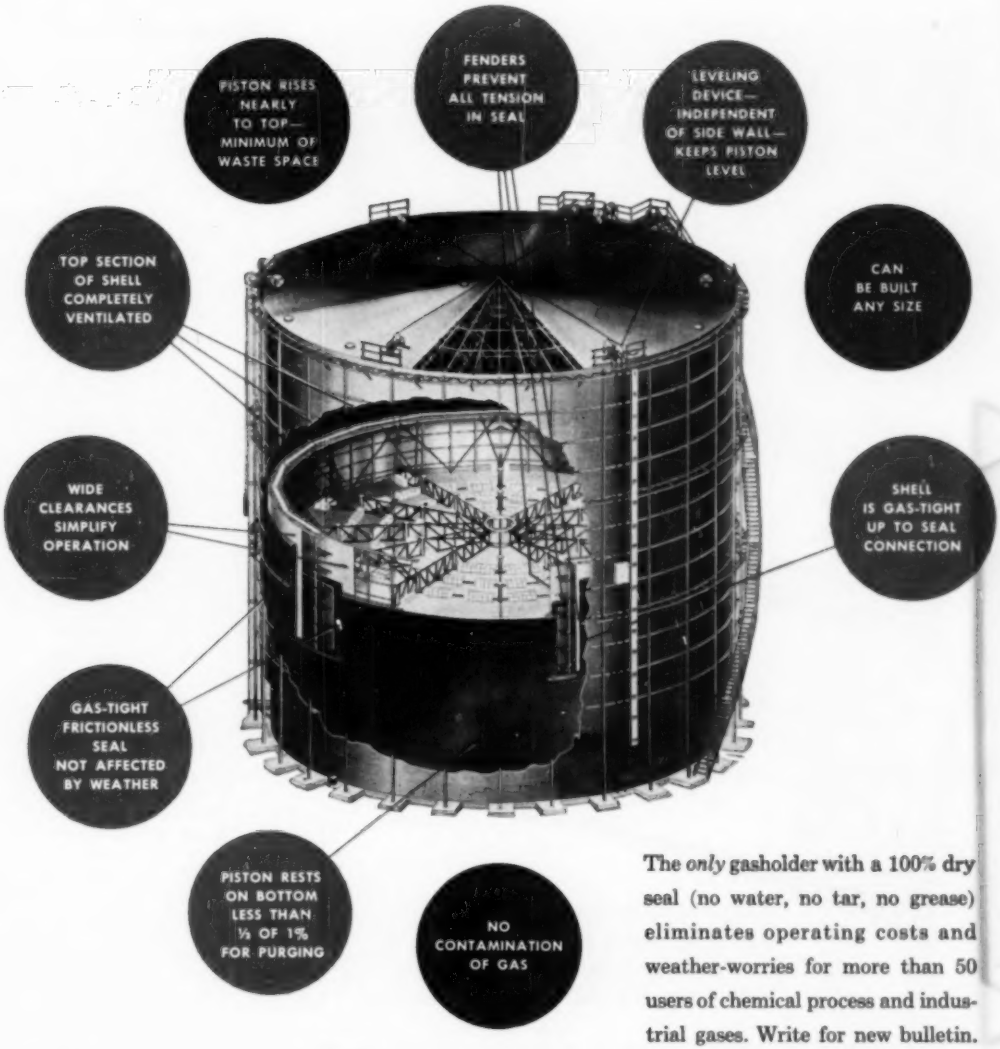
Ohio's largest silica deposit, which

(*Continued on page* 34)

Downtown Cleveland from Lake Erie.. In foreground at left is the Municipal Stadium which seats 80,000 people. Further inland, just right of center is the Terminal Tower.

Left to right: G. W. Blum, chairman, Hotel Arrangements Committee; F. A. Bauman, chairman, Printing Committee.

Left to right: C. E. Ford, vice-chairman, Entertainment; G. H. Metzger, chairman, Plant Trips.


PISTON RISES NEARLY TO TOP—MINIMUM OF WASTE SPACE
FENDERS PREVENT ALL TENSION IN SEAL
LEVELING DEVICE—INDEPENDENT OF SIDE WALL—KEEPS PISTON LEVEL
TOP SECTION OF SHELL COMPLETELY VENTILATED
CAN BE BUILT ANY SIZE
WIDE CLEARANCES SIMPLIFY OPERATION
SHELL IS GAS-TIGHT UP TO SEAL CONNECTION
GAS-TIGHT FRICTIONLESS SEAL NOT AFFECTED BY WEATHER
PISTON RESTS ON BOTTOM LESS THAN ½ OF 1% FOR PURGING
NO CONTAMINATION OF GAS

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CONVERSION EASY—OFTEN ADDS CAPACITY

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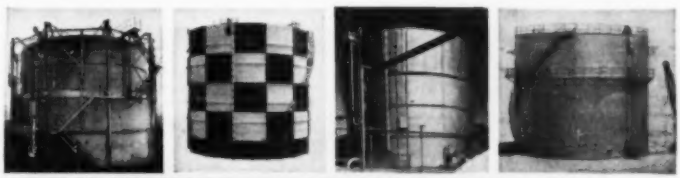

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OFFICES IN PRINCIPAL CITIES
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The Story of a Test

DURALOY

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Test Temperature.....1200°F.
Tensile Strength.....38,200 psi.
Elongation (2")..... 29.5%
Reduction in Area..... 86.1%

That's high quality metal! Metal destined for a high alloy casting which has to meet some pretty rigid specifications!

The story we want to tell here is about our Testing Facilities. We have right in our foundry every conceivable testing facility needed when checking static or centrifugal high alloy castings for industry. Where required, we make complete chemical, metallurgical, and mechanical checks and tests. And have both a 400,000 volt X-ray unit and gamma-ray unit, for checking the final casting for hidden flaws.

As we see it, the only way to assure customers of high quality castings is to have and use all necessary facilities for testing and checking the heat, pour and finished casting.

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CLEVELAND STORY

(*Continued from page 32*)

extends southwesterly across the state, starts in the area. All grades of limestone are available from upper Michigan by lake carrier at low rates. Coal for fuel and processing is available from seventeen major coal beds which are within a few hours' hauling distance. Millions of barrels of oil have been proven in reserve—more than half of which is top Pennsylvania Grade crude. The state also is cultivating more than a million acres of soy beans.

Lake Erie provides an inexhaustible supply of fresh water for processing and plant uses. The lake possesses one of the few remaining supplies of good quality water which may be obtained at an economical cost. A plentiful supply of high-grade dolomite is located in the near-by northwestern portion of the state. At one time, two Ohio counties—Sandusky and Seneca—produced more dead burned dolomite than the rest of the United States combined.

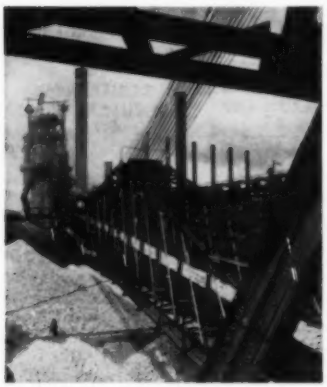
Another factor which has contributed to the area's growth is the availability of adequate dependable electric power. The area is served by an integrated system of three interconnected power plants with a combined capacity of 1,134,000 kw. The Cleveland Electric Illuminating Co. is now installing 375,000 kw. of new generating capacity in a 135 million dollar expansion program.

The industrial growth of Cleveland has been greatly aided by the colleges and universities in the area, which have continued to supply many of the scientists, engineers and businessmen required. Chemical engineering training on a bachelor's level is provided by Case Institute of Technology and Fenn College; in addition, Case carries on an extensive graduate school program leading to degrees of M.S. and Ph.D. Many graduate courses are offered in the late afternoon and evening divisions, providing the opportunity for men in industry to augment their undergraduate course training with advanced work.

Fenn College has a well-established record as a cooperative school; here a student may alternate periods of class room instruction and industrial experience. Baldwin Wallace, John Carroll and Oberlin are primarily liberal arts colleges which are located in the Cleveland area, while Western Reserve University has several undergraduate schools and various graduate professional schools. It does not train students in any engineering field.

Because of the nucleus formed by these and other institutions, the area is developing as a research center. A recent addition was the B. F. Goodrich

Co.'s main research and development laboratory where approximately 200 scientists are exploring rubber, plastics, and chemicals. The Diamond Alkali Co. has just opened a new research center in Painesville. Others with research and development laboratories in the area are Harshaw Chemical, The Standard Oil Company of Ohio, Lubrizol Corp., National Carbon, and the Brush Development Co. Horizons, Inc., a recent entrant in the titanium field, has a laboratory in the area. The Lewis Flight Propulsion Laboratory of N.A.C.A. has 2500 scientists and technicians conducting research in a $66 million



Blast Furnaces, Corrigan McKinney Works, Republic Steel Corp., Cleveland.

laboratory. General Electric has lighting facilities at Nela Park, the famous University of Light.

Various Producers in Cleveland Area. The Painesville-Ashtabula area was pioneered by the Diamond Alkali Co. in 1912 to produce soda ash for glass manufacturing. It now employs about 3500 workers and 150 different chemicals flow from its mile-long plant. At the present time, the company is constructing an electrolytic caustic-chlorine operation to replace the lime-soda process for caustic soda.

The Diamond Magnesium Co., located near Diamond Alkali, has a rated capacity of 18,000 tons/year.

Stauffer Chemical Co. produces carbon bisulfide in nearby Perry, which serves as a raw material for Diamond's carbon tetrachloride and Industrial Rayon.

Also in or near Painesville are Clifton Products, manufacturers of beryllium oxide; A. E. Staley, processors of soy bean oils; and the Dasher Rubber and Chemical Co.

(*Continued on page* 39)

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NEW BJ CHEMICAL PUMPS

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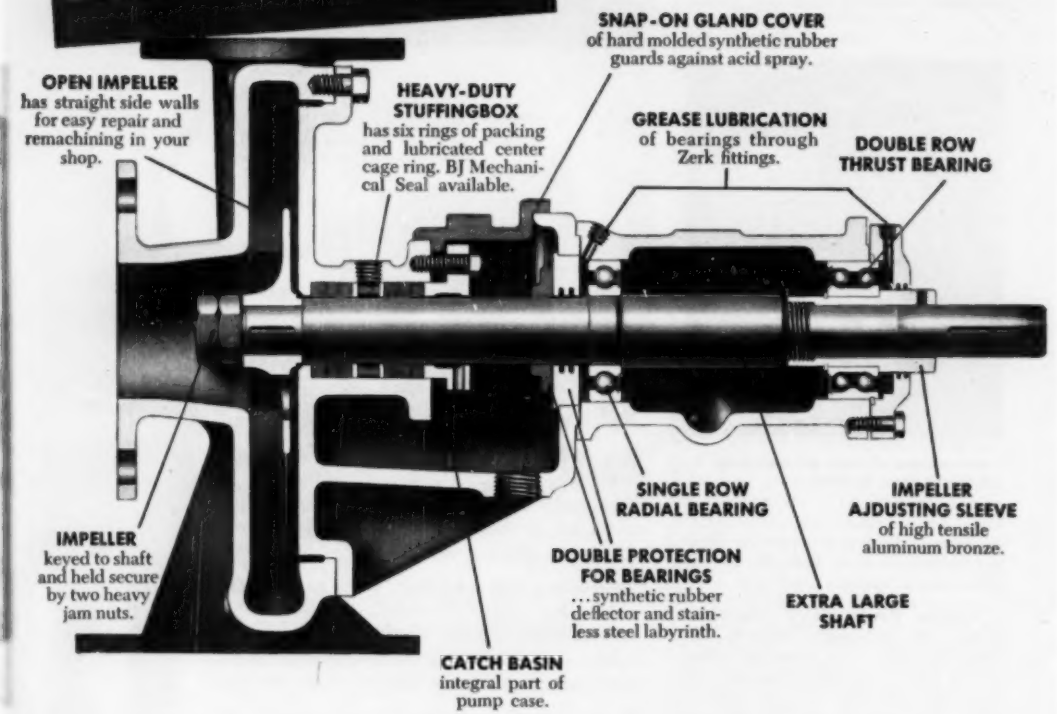
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of hard molded synthetic rubber guards against acid spray.
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of bearings through Zerk fittings.
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of high tensile aluminum bronze.
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keyed to shaft and held secure by two heavy jam nuts.
DOUBLE PROTECTION FOR BEARINGS
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EXTRA LARGE SHAFT
CATCH BASIN
integral part of pump case.

You've asked for them... now BJ introduces these special construction features!

- *Quick and easy dismantling* for inspection and repair without disturbing piping or driver.
- *All parts interchangeable* except pump case and impeller. Four different pump sizes can be used on one basic stuffingbox and bearing bracket assembly.
- *Corrosion-resistant catch basin*—integral part of pump case—guards bearing bracket and base plate from corrosive leakage.
- *Adjusting sleeve* permits compensation for impeller wear—allows easy adjustment without dismantling.
- *Grease lubrication* gives bearings greater protection against acid fumes. Deflector and labyrinth provide double protection against liquid entrance.
- *Cored passages* through impeller web keep stuffingbox under suction pressure.

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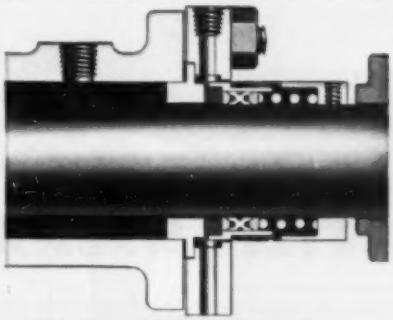
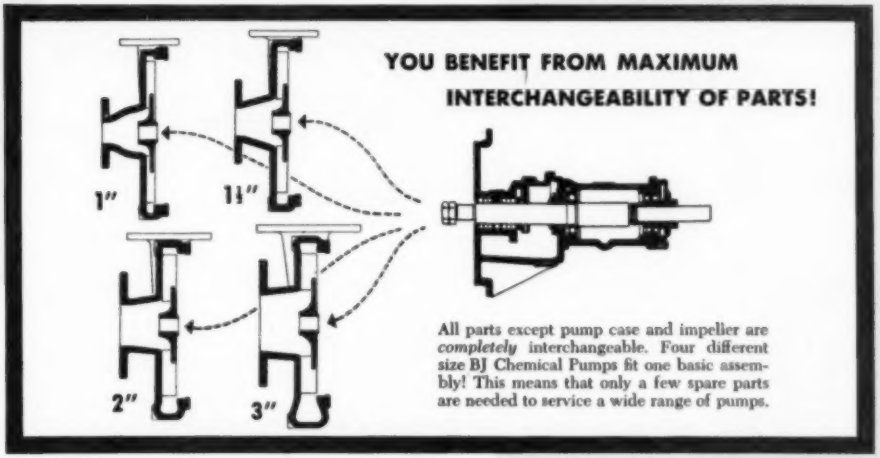
You—the chemical pump user—dictated the design of these new BJ Chemical Pumps. Before Byron Jackson engineered these new BJ models, chemical pump users were asked what features were wanted most. Now these improved features are yours in the new BJ Chemical Pumps. Four pump sizes are available (1", 1½", 2" and 3") with capacities to 450 gpm and heads to 100 feet.

BJ Mechanical Seal also available for protection against leakage. BJ's Type "A" Mechanical Seal is designed especially for the particular demands of chemical pumping. It replaces the packing and provides positive protection against leakage to the bearings or contamination of the pumped liquid. All major parts of this BJ-designed seal are effectively isolated from contact with pumped liquid. Available as special construction, the BJ Mechanical Seal will save you maintenance time and money by eliminating frequent repacking.

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MOBILIZATION REPORT SHOWS PROGRESS IN METAL PRODUCTION

TITANIUM and germanium production, and construction in the atomic energy field are moving ahead rapidly according to information released last month in the Seventh Quarterly Report to the President on the Defense Mobilization Program. Henry H. Fowler, director of the mobilization effort and successor to John R. Steelman, reviewed most of the defense program in the report, which was titled, "New Resources Bring New Opportunities." Three programs were specifically mentioned which are of interest to the chemical field.

The titanium goal for 1955 is production of 10,000 tons of sponge yearly. As of now (Fig. 1) output is 2000 tons. According to the report, "one of the steps toward achieving the titanium expansion goal shown is a Government guarantee to purchase output and an advance of funds for construction of facilities" which when they are completed in 1955 will supply 2700 tons annually, which is some 35% more than the entire supply in 1952. "Because of the potentialities of titanium," the report further states, "research looking toward more economical methods of processing and fabrication has been going forward on an increasing scale since the Korean invasion. Titanium-base alloys already developed are stronger than many present steels. They are 40% lighter in weight, and highly corrosion resistant, especially to salt water."

Raw Materials

Regarding other metals the report stated that "two additional purchasing agents were designed under the Government's program for acquiring columbium-tantalum ores and concentrates for the national stockpile and other defense purposes. This program offers an incentive bonus to producers which doubles the current market price for these scarce ores and concentrates of foreign as well as domestic origin. It is designed to stimulate the search for and development of columbium and tantalum deposits throughout the free world.

"A tax amortization certificate has been issued on facilities which will double present capacity for production of germanium. The demand for this rare metal has increased greatly in the past few years because of its use in electronics. A germanium-using transistor, about the size of a cigarette lighter flint, can perform all the functions of the conventional vacuum tube while requiring one four-hundredth the space and one millionth the electric energy. This development is of special importance to airborne electronic equipment because of the reductions made possible in weight and space. Fifty-five new exploration contracts were executed during the past quarter, increasing the total to 369. Fifteen projects which have received government assistance under the exploration program are already shipping ores of lead, zinc, tungsten, manganese, copper, beryl, and uranium produced as a result of the exploration work.

"The expansion program for a number of materials was stepped up in the last quarter by the establishment of new or increased expansion goals, as shown in Figure 2."

Manpower

Under manpower sources the report revealed that atomic energy projects are now employing almost 3% of the country's contract construction workers, with 73,000 at work in mid-August. More than half are at Savannah River, S. C. Employment in the A.E.C. will continue to rise, the report said, with the construction of the new gaseous diffusion plant at Pike County, Ohio. By the end of 1954, this project alone will use 22,000 employees.

The report is for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at a price of 30 cents.

Titanium expansion will serve growing needs for strong lightweight metals

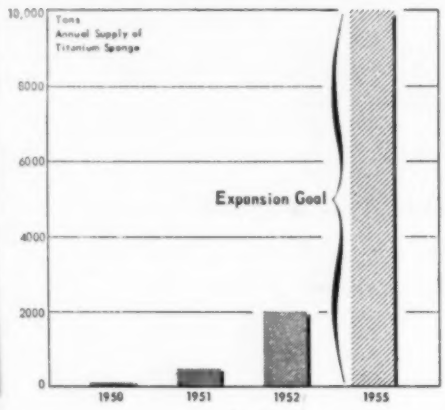

Fig. 1.

New supply expansion goals established for 4 critical materials

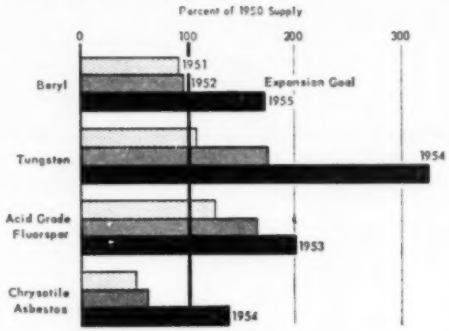

Fig. 2.

ETHYL GRANTS IN CHEMICAL ENGINEERING

Six chemical engineering grants have been made this year by Ethyl Corp. under its expanded program of graduate fellowships. A total of twenty-one grants were awarded, as contrasted with twelve last year; of these, ten are in the engineering field. Recipients of the chemical engineering fellowships are Robert H. Perry, University of Delaware; John E. Anderson, Iowa State College; Albert H. Wehe, Jr., Louisiana State University; Rollin G. Lindsey, Ohio State University; Langley R. Hellwig, University of Texas; and Archie D. K. Knight, University of Tulsa.

(*News continued on page* 41)

CLEVELAND STORY

(*Continued from page 35*)

In Ashtabula, the Electro-Metallurgical Co., a division of Union Carbide and Carbon, which produces ferro alloys and calcium carbide, is doubling its capacity. This plant is one of the world's leading producers of calcium carbide. The Linde Air Products Co., another division of Union Carbide, is now constructing a seven-million tonnage plant to supply the major steel industries with oxygen for steel production.

The National Distillers Chemical Corp. recently completed an eleven-million-dollar metallic sodium chloride plant here. The Hooker Detrex Co. is located adjacent to National Distillers from whom it obtains chlorine and Electro-Met from whom it receives acetylene for the production of perchlorethylene.

Interior of Lubrizol pilot plant.

Barium and Chemicals, producers of high-purity barium and strontium compounds, is located in Willoughby, Ohio.

The Lubrizol Corp., which manufactures chemical additives for the oil industry, is located in Wickliffe. These products are for use in transmission and crankcase lubricants, cutting oils, and other petroleum products.

The Standard Oil Company of Ohio has put on stream a new Thermofor Catalytic Cracking Unit with a capacity of 18,000 bbl./day. This unit has a 50% increase over the Houdry Catalytic Cracker which was completed in 1944 and which it now replaces. Standard Oil has been continually improving and increasing its facilities and has spent more than $25 million on new plants in Cleveland in the past two years.

The Grasselli chemical department of Du Pont has had a sulfuric acid plant in Cleveland for about eighty-five years. The American Agricultural Chemical

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Lewis Flight Propulsion Laboratory, National Advisory Committee for Aeronautics, Cleveland.

Co. and the general chemical division of Allied Chemical also have sulfuric acid plants in Cleveland.

Research Center on Aircraft Systems. The Lewis Flight Propulsion laboratory of the National Advisory Committee for Aeronautics has a laboratory staff of 2500 scientists and technicians, housed in seventy-seven buildings on a 200-acre site adjacent to the Cleveland airport. Problems investigated include fuels, lubricants, turbines, compressors, corrosion, materials of construction and aerodynamics. The icing research tunnel permits study of flight characteristics under ice-forming conditions for the engines, propellers, and aircraft components. It is, today, believed to be the world's largest center for research on aircraft propulsion systems.

Industrial gases are produced in Cleveland by Linde Air Products, Air Reduction, and The Burdett Oxygen Co. These companies produce oxygen and acetylene for the large metal working markets in Cleveland. The Ohio Chemical and Surgical Equipment Co., a division of Air Reduction, manufactures anesthetic and therapeutic gases.

Cleveland has six pharmaceutical companies, the most outstanding being The Strong, Cobb and Co. which traces its founding to 1833.

The Harshaw Chemical Co., one of the nation's leading manufacturers of pigments, catalysts, electroplating chemicals, hydrogen fluoride, and heavy metal soaps, maintains plants both in Cleveland and nearby Elyria. Cleveland's prominence in the plating field is further advanced by the McGean Chemical Co., which produces a widely diversified line of electroplating chemicals in addition to many chemicals for the ceramic and paint industries.

The National Carbon Co., a division of Union Carbide and Carbon Corp., was established in 1886. The Edgewater works in Cleveland is the largest factory in the world devoted to the manufacture of primary batteries. National Carbon's research facilities, founded in 1902, cover all phases of primary batteries and carbon products, as well as research on motion picture optics, etc.

Cleveland is also represented in the battery field by the Willard Storage Battery Co.

One important company in Cleveland that may not ordinarily be thought of as a chemical industry is the General Electric Wire Works which produces the rare gases Krypton and Neon and by-product, oxygen. This company also uses hydrogen which is obtained from the chlorine-caustic cells of the Columbia Chemical Co. in Barberton, Ohio. Columbia-Southern Chemical Corp., a subsidiary of the Pittsburgh Plate Glass Co., is a large producer of alkalies and industrial chemicals.

Other companies in Cleveland include the Brush Beryllium Co., producers of beryllium metal and beryllium alloys; The Harris-Seybold Co., manufacturers of lithographic chemicals; The Parker Appliance Co., producers of synthetic rubber compounds and plastics; The Reilly Tar and Chemical Co., and The Werner G. Smith division of Archer-Daniels-Midland Co. Paper is processed in the area by the Chase Bag Co. in Chagrin Falls, and by the Jaite (Ohio) Paper Co.

Studies have been undertaken of Cleveland's industrial diversity for the planning of the future. Currently only one other county in the United States possesses as high a concentration of manufacturing as Cuyahoga County, upon which about 56% of the employment depends. About 70% of this manufacturing depends upon five types of durable goods manufacturers: machinery primary metal, transportation equipment, electrical machinery, and metal products. Attracting of new industry, especially chemicals, is mutually desirable for both the community, for a more balanced economy, and for chemical industry, to avail itself of the central location for raw materials and markets, minimum transportation expense, and cooperative labor. Cleveland, a city of aggressive industrial management and desirable residential areas, assures its future growth as one of the great chemical centers of the country.

Acknowledgment

The author thanks the Cleveland Electric Illuminating Co. for assistance in securing information and photographs.

Meeting Notes

Just as we were about to go to press, the Cleveland committee informed us that John L. Collyer, president, B. F. Goodrich Co., will address the Institute at the Awards Banquet.

The paper "Carbon Dioxide Absorption by Hot Potassium Carbonate Solutions" listed last month under the General Technical Program for Monday, December 8, at the Cleveland meeting is by H. E. Benson, J. H. Field, and R. M. Jimeson.

The author of last month's story on the Cleveland Meeting was R. L. Savage.

Cleveland Museum of Art.

NEWS

(*Continued from page 38*)

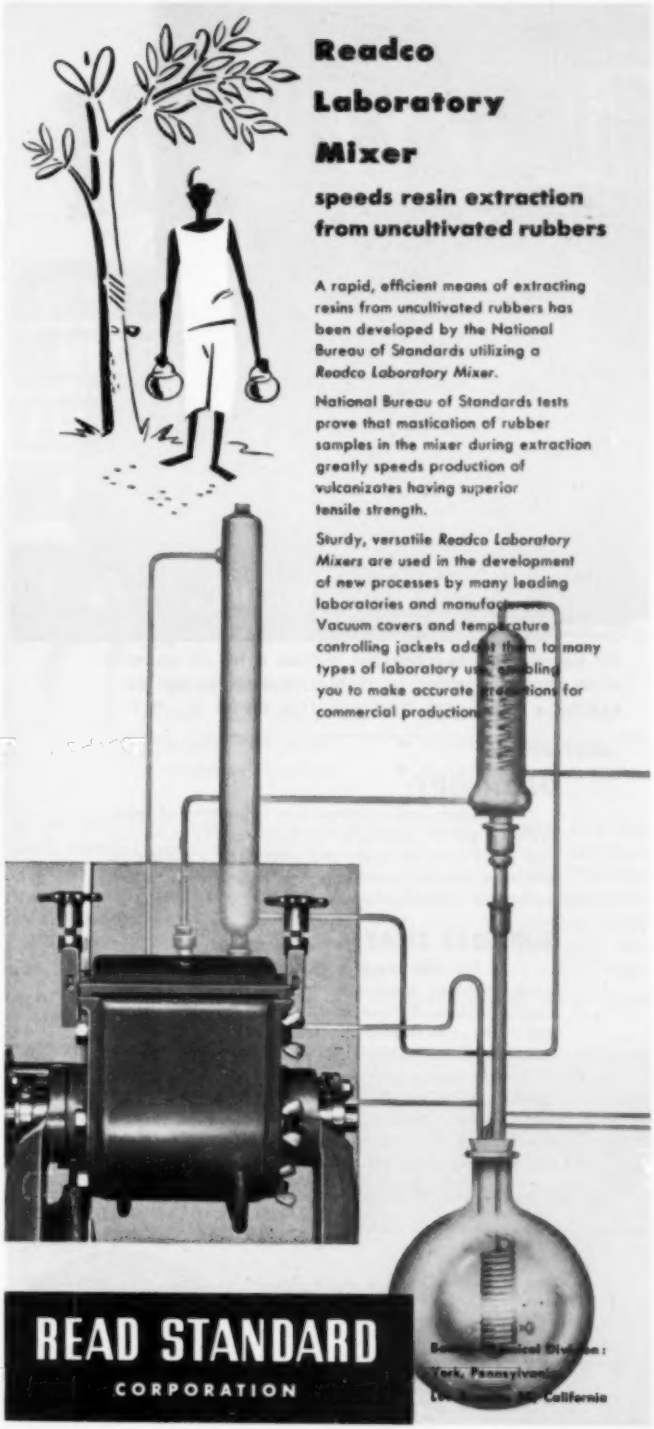
DUCTILE IRON APPLICATIONS INCREASING

After three years of commercial development, ductile iron has found numerous applications in industry, including the chemical process group, according to International Nickel Co. executives who recently demonstrated its properties at a press conference. Its high mechanical properties and excellent ductility, they said, make it superior to gray cast iron where strength and resistance to shock are important; yet it has desirable casting machinability and characteristics. The International Nickel Co. licenses the manufacturing process to foundries throughout the world.

Pouring heat of ductile iron at International Nickel research laboratory foundry, Bayonne, N. J.

Ductile iron's resistance to impact makes it suited to cast mixing and pumping impellers, pump casings, and similar items, and pipe valves and fittings from the material may prevent failures due to vibration or thermal stresses. The weldability of ductile iron permits, among other things, the application of hardening materials to the wearing surfaces of screw-type processing units, and its resistance to pressure makes possible the construction of cast pressure vessels. As an example of the application of ductile iron to the chemical industry, it was stated that caustic pots cast of this material outlive gray iron units three to four times.

Where corrosion resistance is a consideration, ductile iron can be alloyed with nickel or molybdenum, and in addition a ductile Ni-Resist can be obtained.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*Boiling point of helium.

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SPEIDEN INTERESTS SOLD

International Minerals & Chemical Corp. has sold the name of Innis, Speiden & Co., Inc., and its resale chemical business to Berkshire Chemicals, Inc., of New York. International bought Innis, Speiden in July, 1951. Malcolm H. McAllister, president of Berkshire, has also been elected president of Innis, Speiden & Co., Inc. Of the Speiden business, International now has only the electrolytic plant and facilities at Niagara Falls, N. Y.

"Parts of Innis, Speiden," said A. Norman Into, vice-president of International's potash division, "consisting of a gum and wax business with a plant at Jersey City, an insecticide business and a general resale chemical business, did not follow the type of business conducted by International Minerals & Chemical Corp.

"During the past several months, therefore," Mr. Into stated, "International has been divesting itself of these activities."

Innis, Speiden's wax and gum business has been sold to Morningstar, Nicol, Inc., of New York, and the insecticide segment has been purchased by a group of former employees of Innis, Speiden who formed the Lavarcide Products, Inc. International will continue to make at Niagara Falls certain of the insecticide products for Lavarcide Products, Inc.

International Minerals plans to spend more than a million dollars at the Niagara Falls plant for improvements which will increase production of chemicals and chlorine products by about 25 per cent.

SUBSTITUTES FOR NATURAL GAS

Substitutability of oil gas for natural gas is studied in an Interim Report to the Institute of Gas Technology by D. L. Nicol, R. A. Brown, and H. R. Linden. The report is part of the larger research problem, sponsored by the American Gas Association, of the manufacture from oil and coal of gases that will be completely interchangeable with natural gas.

The problem arises from the widespread conversion to natural gas in the United States and the consequent need for manufactured gas that can be substituted for natural gas in peak or emergency periods. At present the gases are not interchangeable.

The techniques discussed in the present report, which deals with the maximum per cent of oil gas in the oil-natural-gas mixture that would give satisfactory performance on selected appliance burners, are (1) mixing or dilution

with inerts, (2) reduction or removal of specific aromatic hydrocarbons through scrubbing, freezing, or compression, (3) control of severity of cracking in the production of oil gases, and (4) reduction or removal of unsaturated hydrocarbons and hydrogen through catalytic autohydrogenation.

The report may be purchased from the Institute of Gas Technology, Chicago, Ill., for $2.50.

PRESSED STEEL TANK, DOWNINGTOWN MERGE

Herman Merker, president of Pressed Steel Tank Co., Milwaukee, Wis., and Penrose M. Davis, president of Downingtown Iron Works, Inc., Downingtown, Pa., announced jointly last month the merger of the interests of the two companies through the acquisition by Pressed Steel Tank Co. of all outstanding capital stock of Downingtown Iron Works.

"Downingtown Iron Works," Mr. Merker said, "retains its existing corporate structure, and will be operated as a division of Pressed Steel Tank Co. No changes in management or personnel are contemplated."

Products of both companies are used by the chemical, food, oil and other industries.

UNLICENSED ENGINEERS TO LOSE IN LAWSUITS

Unlicensed engineers in Pennsylvania who contract to perform engineering work will be unable to maintain successfully a lawsuit to recover fees, in the opinion of John M. Weiss, chairman of the A.I.Ch.E. Committee on Professional Licensing. This conclusion was reached after studying the recent ruling of a Pennsylvania County Court in which an unlicensed individual claimed to be an industrial engineer with special knowledge in instructing and guiding a company in special work. The suit to recover fees was denied by Chief Justice Drew because the consultant was engaged in the practice of industrial engineering contrary to law and "the Courts will not lend their aid to enforcement of unlawful contracts."

PULP AND PAPER FOUNDATION REPORT

The Pulp and Paper Foundation of the University of Maine recently issued its second annual report, which includes a summary of the Foundation's research projects, a list of industry contributors of scholarships and special gifts, and an outline of the five-year curriculum in pulp and paper management.

(*More News on page 54*)

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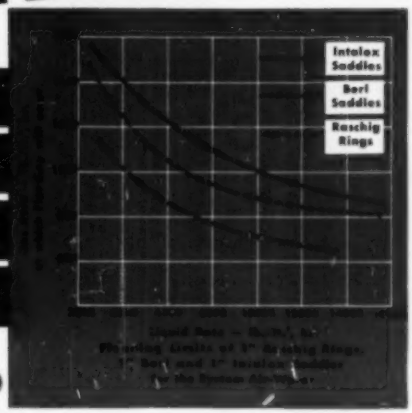

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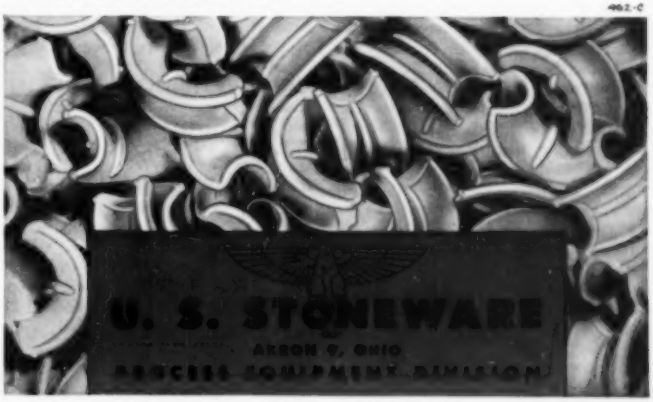

MARGINAL NOTES

News of Books of Interest to Chemical Engineers

Revision Proves Worth While

Unit Processes in Organic Synthesis—Fourth Edition. P. H. Groggins, Editor-in-Chief. McGraw-Hill Book Co., New York (1952). 937 pp., $12.50.

Reviewed by J. C. Weaver, Jr., Process Section, Stanolind Oil and Gas Co., Brownsville, Tex.

THE present edition of this well-established text and reference work represents a comprehensive revision of its predecessor. The original style, comprising a review of each unit process by one or more authorities, has been retained. In line with current teaching in chemical engineering, increased emphasis has been placed on reaction kinetics and thermodynamics. In some cases, the sections on these subjects have been prepared by new contributors from industry or government. Extensive references to the B.I.O.S. Reports on German chemical-industry practices prior to the end of World War II have been included, many of which contain invaluable information. Ready availability of these references, classified by unit process, will be appreciated by many industrial chemists and chemical engineers. This feature and the improved treatment of the subjects of kinetics and thermodynamics are believed to be the most significant additions as compared to the previous edition.

The addition of a chapter devoted to a comprehensive review of the Oxo reaction is appropriate. This contribution will be particularly welcomed by personnel employed in laboratory research in this field and engineers engaged in preliminary process evaluation studies.

Increased emphasis has also been placed on the synthesis of petrochemicals, another change which, in the opinion of this reviewer, is highly desirable.

Assuming, briefly, the role of a constructive critic, there still appears to be some room for improvement in future editions. For example, the types of flow sheets, and equipment diagrams, and the extent of their use vary widely among different chapters. Examination of some of the chapters comprising subjects of which the reviewer has detailed knowledge reveals, in some instances, that outmoded procedures or incomplete descriptions have been given. The desirability of employing a still larger number of contributors to supply specialized information to the authors of each particular chapter is suggested. Comparison of the status of the unit processes as presented in the subject text with the annual Unit Processes Reviews of Industrial and Engineering Chemistry shows generally a definite lag of the former. This situation is undesirable, and must have presented a problem to the authors, since an annual review may report patent and other developments of little long range industrial importance.

Furnishes Needed Data

Glycols. Edited by G. O. Curme and F. Johnston. ACS Monograph 114. Reinhold Publishing Corp., New York (1952). 389 + xii pp., $12.00.

Reviewed by Fred Kurata, Prof. Chem. Eng., Univ. of Kansas, Lawrence.

THIS book, prepared by the research staff of Carbide and Carbon Chemicals Co. and edited by Messrs. Curme and Johnston, fills a critical need for a complete review on glycols. It is a comprehensive treatise on ethylene and propylene glycols, their condensation products, and on ethylene and propylene oxide. The commercial history of glycols and oxides, their manufacturing techniques and their physical and toxicological properties are treated in separate chapters. The application and use of glycols and their derivatives as well as some of their analytical and test methods are also separately treated.

A considerable amount of data given in the chapters on physical properties of glycols and oxides has not been heretofore available. In addition to the properties of pure constituents, vapor-liquid equilibria data and properties of mixtures of glycols with other compounds are included, as are a limited number of thermodynamic properties.

Another major contribution of the authors is the comprehensive literature survey.

Aside from the physical properties, the balance of the discussion and information is largely qualitative in nature. Because of the unavailability of process data, it is recognized that much information of this sort must be general. It is believed, however, that the authors may well have included more of the pertinent quantitative data which are available in the literature.

"Tools" of Chemical Engineering

Chemical Engineering Techniques. B. E. Lauer and R. F. Heckman. Reinhold Publishing Corp., New York (1952). 496 pp., $6.00.

Reviewed by David E. Pierce, Chief Eng., General Aniline & Film Corp., New York.

A NEW approach to the teaching of chemical engineering is presented in Lauer and Heckman's book. The authors believe that "chemical engineering practice is the application of a number of rather well defined, inter-related, and easily classified techniques," and that these techniques should be presented to students as "tools of their profession."

The purpose of the book, therefore, is to point out the basic objectives of chemical engineering and to present in a qualitative way the techniques available for achieving those objectives. The quantitative treatment of the problems of the profession is left to the other books and handbooks available.

Six unit tasks of chemical engineering are recognized: (1) assembly of raw materials; (2) preparation of raw materials for reaction; (3) utilization of energy; (4) control of conditions affecting the reaction; (5) separation of the products; (6) preparation of the products for shipment, for further use, for sale, or for storage. Each of the six sections treats one of these tasks. The chapters of each section cover the subclassifications or "unit subtasks." For example in Section V, "The Separation and Purification of Materials," there are nine chapters dealing with the nine types of separations which may arise in handling matter in any two of the three states (solid, liquid, and gaseous). Thus, one chapter covers the subtask of separating liquid from liquid, another of separating solid from gas, etc.

The brief view of how a great many things are done in the chemical industry and of the terminology that is used in describing those operations will make this work useful to the student. He will find some of the explanations less than crystal clear because of the absence of a drawing of the specific item being described, but will appreciate the impossibility of illustrating every piece of equipment mentioned. There are, however, many illustrations and a index.

(*More Marginal Notes on page 62*)

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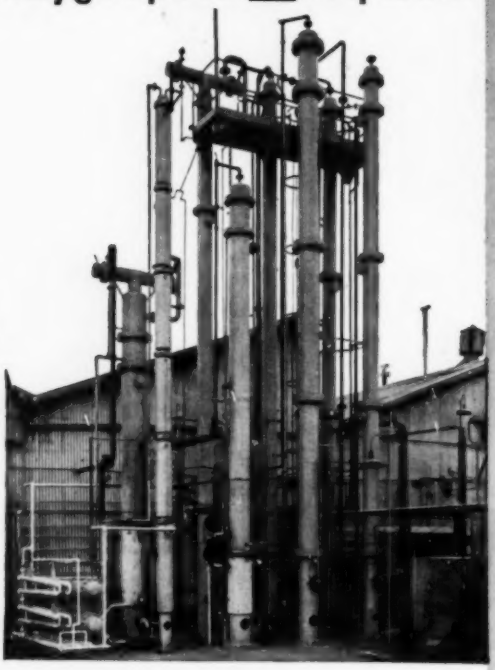
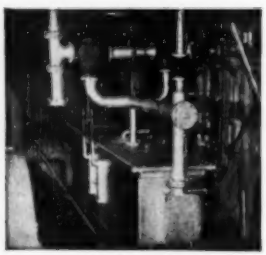


Wulff Process Recovery and Purification section. In operation over 19 months, the plant has sold acetylene commercially for the past 10 months.



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2 • LUBRICATED VALVES. Lubrication application system for all valves. Lincoln Engineering Co. High-pressure, portable lubricant pump, hand gun and line of extreme pressure grease fittings.

3 • PETROLEUM TESTING EQUIPMENT. Technical Equipment Co. A.S.T.M. and Federal petroleum products testing apparatus. Special features and design improvements include replacement of orifice flowmeters by rotameters, mercury temperature regulators by resistance thermometers, etc. List of apparatus, prices and other information.

4 • FLUID CONTROL VALVES. A file of loose-leaf dimensional data sheets on a line of fluid control valves from Hoke, Inc.

5 • ADMITTANCE METER. General Radio Co. bulletin on their U-H-F admittance meter. Simple and direct operation principle, adaptable to many types of measurements, wide-frequency range, direct reading, balanced impedances.

6 • CROWN COUPLINGS. A flexible coupling by De Laval Steam Turbine Co. Information on construction, horsepower ratings, speeds, applications and selection.

7 • FURNACES. Submerged electrode, salt-bath furnaces described and illustrated in new folder from Ajax Electric Co. List of seventeen ways in which heat-treating efficiency increased on ten specific applications. Sizes, temperature ranges, other details listed.

8 • WATER FILTERS. Pressure-type water filters from Graver Water Conditioning Co. Variety of valve and piping arrangements. Diagrams, cutaway views, tables on dimensions, weights, and capacities.

9 • PUMP GUIDE. Tuthill Pump Co. offers new pump guide. Chart gives model, service, capacity, packing, mountings and special features of each type.

10 • 10A • TACHOMETER HEADS. (10) Technical data sheet from Metron Instrument Co. covering heavy duty speed-measuring heads, rotational or linear. Head shaft can be rotated from 100-10,000 rev./min. for full-scale reading. *(10A)* Data sheet on series for measuring low rotational or linear speeds.

11 • HEAT EXCHANGER. A Griscom-Russell Co. bulletin on twin G-Fin sections used in process fluid heaters, condensers, heat exchangers, etc., in the chemical process industry. Tables and specifications.

12 • AGITATORS. Agitators - propeller, open impeller, radial propeller,

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etc.—also an agitator design for quick dispersion of liquids, gases and solids. Brochure from Struthers Wells Corp.

14 • ***TALL OIL ESTERS.*** From the Tall Oil Assoc. a bulletin covering the use of tall oil in the manufacture of esters. Gives advantages, uses of esters, monohydric, polyhydric, mixed and monesters, testing methods, etc.

15 • ***ION-EXCHANGE RESINS.*** A bulletin on Amberlite IRA-410 from Rohm & Haas Co. Notes on hot process, ion-exchange softening, includes formulas.

16 • ***TEL-A-PIPES.*** Self-adhering, positive identification for cable, conduit, and pipe from Westline Products Division, Western Lithograph Co. Colors to differentiate types of materials. Easily applied. 200 types available.

17 • ***PYROMETERS.*** Assembly Products, Inc., indicating pyrometers, for panel-mounting and portable use. Nine temperature ranges cover −200 to +3000°F. Also −130 to +1650°C.

18 • ***KARBATE.*** Towers, 12 to 24 in. of Karbate impervious graphite from National Carbon Co. Construction diagrams, specifications, dimensions.

19 • ***METROGRAM BALANCE.*** High capacity precision-weighing instrument, by Arthur S. LaPine & Co. Sensitivities from ± 10 mg., weighs in out-of-level positions. For testing, counting, check weighing, etc. Illustrated bulletin.

20 • ***CROLOY TUBING.*** Two stainless tubing steels from Babcock & Wilcox Co. Resistant to corrosion and oxidation, hardened by heat treatment. New technical data card. Information on mechanical properties, forging, welding, physical properties, corrosion resistance.

21 • ***INDUSTRIAL CHANGE ROOMS.*** The design and layout of industrial change rooms with recommended standards, designing dimensions and selected details in a 16-page illustrated booklet from The Moore Co. Equipment illustrated, specimen layouts and technical data.

22 • ***SPEED REDUCERS.*** Dodge Mfg. Corp. speed reducers, rolling bearings, V-belt drives, couplings, sleeve bearings, etc. One to 43 hp., speeds 12 to 330 rev./min., tables for single and double reduction speed reducers.

23 • ***SPRAY DRYERS.*** Zizinia spray dryers engineered by Foster D. Snell, Inc. For use on powdered soaps, sugar, coffee, milk, eggs, chlorophyll, etc. Evaporation rates up to 2000 lb./hr., three sizes, stainless steel, carbon, Monel, etc., temperature range to 700° F.

24 • ***EQUIPMENT.*** A 36-page pocket booklet from Ingersoll-Rand, describing products, air and electric tools; compressors; engines; blowers; pumps, etc.

25 • ***AGITATOR.*** Denver Equipment Co. new bulletin on Super-Agitator. Drawings illustrate operation and construction of agitator and conditioner. Specifications and data.

26 • ***LIQUID AIR CONTAINERS.*** Containers and flasks for liquid air, oxygen, nitrogen, etc., from Superior Air Products Co. A new storage and transport type container and a liquid helium-liquid hydrogen container. Capacities from 5-200 l.

27 • ***LABORATORY PLANNING KIT.*** Fisher Scientific Co. kit to permit custom installations without blueprints. Package contains scaled cutouts, representing twenty-one ready-made, preengineered steel furniture units. Complete catalog of unitized furniture included.

28 • ***HOSE CLAMPS.*** Hose clamps for industrial hose application. Bulletin from Hose Accessories Co. Large range of sizes and types, hose couplings, accessories, etc.

29 • ***BOILER.*** Kewance - Ross Corp. describes new round R boiler for oil, gas, and stoker firing. Steam radiation of 400 to 900 sq. ft., water radiation 640 to 1440 sq. ft. Provision for automatic control, special combustion chamber for oil firing, conversion from one fuel to another, cutaway view, etc., in covering bulletin.

30 • ***GEAR MATERIALS.*** International Nickel Co., Inc., bulletin on nickel steel and cast iron, and two new gear

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31 • FORK TRUCKS. Gasoline or Diesel powered handling equipment of various types. Up to 10,000-lb. capacity from Yale & Towne Mfg. Co. Standardization allows installation of either type power plant.

32 • PROPORTIONING PUMP. %Proportioneers, Inc.% bulletin on Chem-O-Feeder proportioning pump. Package assembly, self-contained lubrication. Specifications, operating data, etc.

33 • AROMATIC AMINES. Six new aromatic amines, phenyl diethanolamine, phenyl ethyl ethanolamine, 2,5-diethoxyaniline, etc., listed in bulletin from Tennessee Eastman Co. Data sheet covers specifications, solubility, shipping.

34 • COPPER INDEX. Two-section publication from American Brass Co. considers copper and copper alloy. Included are A.S.M.E., A.S.T.M. and Federal specifications, as well as Army and Navy.

35 • CHEMICALS. Michigan Chemical Corp. catalog covers line of industrial, pharmaceutical and agricultural chemicals. Information on specifications, formulas, containers, shipping regulations, etc.

36 • FLOOR PATCH. An easily applied, quick-setting instant-use floor patch from Flexrock Co. For use on flooring, walls and foundations, roofing. Takes any load.

37 • SCREEN CHANGER. F. R. Hannon & Sons announce a new quick-change attachment which permits rapid and easy change of screen cloth in electric screen heaters. Heaters covered in detail.

38 • UNIFLOW EQUIPMENT. Industrial water conditioning subject of folder from Uniflow Mfg. Co. Proposed system, general specifications, etc. Covers treatment of hardness, sediment removal, and acid rectification.

40 • INDUSTRIAL APPAREL. Now industrial apparel of Orlon. Are acid, chemical, grease, and dirt-resistant. Hold shape, easily laundered, quick drying. Bulletin from Worklon, Inc. illustrated with types available. Give charts, exposure tests, etc.

41 • AUTRONIC CONTROLLERS. Miniature electronic system for control of pressure, temperature, flow, and level by Swartwout Co. Bulletin shows types, gives standard adjustment ranges, maintenance, and service features.

42 • COMPRESSORS. Compressors by Pennsylvania Pump & Compressor Co. for air or gas. Air delivered free of oil, uses steel-backed carbon cylinder-liner, nonlubricated pilot and unloader.

43 • CONTROLLERS. Thermo Electronic signaling temperature controllers and resistance bulbs for use with ovens, tanks, molding machines, stills, etc. from Thermo Electric Co., Inc. Ranges, advantages, types, diagrams, etc., included.

44 • ELECTROLYSER. Electrolytic cells for manufacture of hydrogen and oxygen, Bamag pressure bipolar type, available from General Industrial Development Corp. Illustrated bulletin gives information on operation, a lay-out, schematic drawing and complete technical data.

45 • PROCESS EQUIPMENT. Custom-built, heavy-duty chemical process equipment from Bethlehem Foundry & Machine Co. New catalog lists facilities, types of equipment, cutaway drawings, temperature charts, etc.

46 • CONVEYORS. Four basic types of conveying systems built by Fuller Co. For conveying materials, mixing and blending raw materials, etc. Special features illustrated with diagrams, illustrations, etc.

47 • COOLING TOWERS. An 8-page bulletin from the water cooling division of Binks Mfg. Co. on several types of cooling towers. Complete specifications, cutaway blue print, selection table for air conditioning, typical performance data, etc.

48 • SEAMLESS TUBING. Seamless mechanical tubing of Babcock & Wilcox Co. For design engineers in determining type to use. Outlines differences in methods of production finish, tolerances and tubing cost. Seamless, welded, in carbon, alloy and stainless.

49 • SCALES. Harvard trip balance and triple beam balance scales new with Ohaus Scale Corp. Bulletin covering each type includes capacities, features, specific gravity, etc.

50 • PEROXYGEN CHEMICALS. Potentialities of peroxygen chemicals in seed treatment are covered by Buffalo Electro-Chemical Co., Inc. Removal of seed coat, complete separation of husk and endo-sperm without mechanical operation, short treating time, etc.

51 • ELECTRON MICROSCOPE. A new electron microscope with a 50-kv. accelerating potential, resolving power to 100 Å, photographic magnification to 40,000 and other features described in a brochure from Radio Corporation of America.

52 • PROPORTIONING PUMPS. A new chemical proportioning pump by Neptune Pump Mfg. Co. Used in boiler feed water treatment, dry cleaning, bottling, and other plants requiring fluid control. Simple design, controlled feeding, special ¼-hp. capacitor and 1750 rev./min. motors featured.

53 • AUTOMATIC SCALE. A catalog sheet from Thayer Scale & Engineering Corp. on automatic filling scales. Diagram, performance details, and specifications.

54 • FANS, BLOWERS, ETC. Standard Electric Mfg. Co., Inc., catalog covers its line of fans, pumps, agitators, and

blowers. Each item in book illustrated. Specifications, price, and stock list.

55 • ***PROPORTIONING SCALE.*** For use in bulk weighing, an automatic weighing, bagging, and proportioning scale from Richardson Scale Co.

56 • ***COATINGS.*** Goodall Rubber Co. line of coatings, liners, and pipe from rubber, neoprene, etc. Variety of sizes and shapes available. Table of concentrations and maximum temperatures given.

57 • ***TECHNO MOTOR.*** An alternating current starting motor of 110, 220, or 440 v. a.c., ready to start quickly, minimum maintenance cost, capable of starting engines up to 1500 cu-in. displacement, from Techno Electric Co.

58 • ***REGULATORS.*** Fisher Governor Co. regulators and controllers. Custom built to operating requirements. Variety of types and sizes, described and illustrated.

59 • ***PROCESS EQUIPMENT.*** Equipment for those industries in which drying, screening, and pressing are essential. New loose-leaf book from Davenport Machine & Foundry Co. with diagrams, photos, dimensions and necessary details of company line.

61 • ***RESEARCH ORGANIZATION.*** Sam Tour & Co., Inc., an organization of consulting and development engineers list services and facilities made available by them in new bulletin.

62 • ***DIAPHRAGM VALVES.*** New bulletin describing advanced type diaphragm control valves from Kieley and Mueller Inc. Claimed to have advantage of accessibility because of open yoke. Sizes from ½ to 16 in. Details of construction, etc., given.

63 • ***MERCURY POOL.*** First issue of a two-page bulletin by Micro Switch a division of Minneapolis-Honeywell Regulator Co. Issue features new Honeywell embedded mercury switch, and describes others in line. Gives examples of 900 types available.

64 • ***TURBINE PUMPS.*** For vertical service in industry, agriculture, mining, and municipalities, Fairbanks-Morse & Co. turbine pumps. Bulletin describes oil and water lubricated types, semi-open and enclosed impellers, types of drives, capacities, etc.

65 • ***HOT WATER HEATERS.*** Instantaneous hot water heaters by Pick Mfg. Co. available in seven standard sizes for both direct and accumulator application. Bulletin stresses process savings.

66 • ***CRUSHER.*** American Pulverizer Co. on rolling ring-metal turnings crusher for capacities up to 1½ ton/hr. Features less storage space, shredder ring, manganese steel grate bars, mounted or unmounted, 25-30 hp.

67 • ***BOILER WATER CONTROL.*** Boiler water impurities and their control are the subject of 34-page booklet from Henszey Co. Covers all phases.

68 • ***FILTER PAPER.*** For industrial and laboratory users of filter papers, descriptive catalog from The Eaton-Dikeman Co. Grades for light and heavy funnel work, filter presses and filter machines, etc.

69 • ***PROTECTO SPRAY.*** Grinnell Co. of Canada, Ltd., with a new bulletin on automatic Protecto spray for control of fire with less water. For wide variety of hazards. Permits release of spray at 135°-500° F., as required, orifices ¼-½ in. Underwriter approved.

70 • ***TANKS.*** Industrial tanks for acid, plating solution, bleach, etc. Catalog and test report on line of chemically-resistant tanks from The Chemical Corp. Fiberglas mat impregnated, bonded with polyester resins. One-piece unit.

71 • ***ALLCHEM PUMPS.*** Eco Engineering Co., division of Economy Faucet Co. leaflet on industrial process pumps. Two sizes, Teflon impellers, bearings, packings. Operational requirements, fittings, etc., described.

72 • ***MAGNETS.*** For positive removal of tramp iron and steel permanent magnetic separators by The Homer Mfg. Co., Inc. Typical applications and operations shown.

73 • ***MIXERS.*** Equipment for mixing pastes, liquids, powders, etc., in The J. H. Day Co. bulletin. Dimensions, capacities, photographs, etc., given.

74 • ***BLENDERS.*** Gemco processing and mixing equipment for use in handling ceramic mixtures, pharmaceuticals, chemicals, metal powders, plastics, etc. General Machine Co. of N. J. leaflet. Details of construction, operation, working capacities, etc., listed.

75 • ***PERSONNEL MATERIALS.*** Science Research Associates have prepared a catalog of personnel tests to aid in selection of employees, reduction in employee turnover, improved operating efficiency, etc. Covers complete field of available literature and tests.

76 • ***KEM ROCK.*** For use as working surfaces, table tops, sinks, etc., in areas exposed to acids, alkalies, solvents, heat, and abrasion, Kewaunee Mfg. Co. describes Kem Rock in leaflet. Material is porous stone, impregnated and coated with synthetic resin, baked at high heat.

79 • ***INSTRUMENTATION.*** Instrumentation, quarterly publication from Brown Instruments Division, Minneapolis-Honeywell Regulator Co. on material of interest for Ch.E. in control work.

80 • ***PRESSURE GENERATOR.*** Milton Roy Co. "aiROYmetric" pressure generator for hydrostatic testing of forgings, castings and tubings, vacuum pumps, etc. Automatic, pressures 25-170 to 4000-25,000 with ordinary air supply.

81 • ***GRID HEATERS.*** D. J. Murray Mfg. Co. show grid heaters. Construction details, data given on these plant heaters.

82 • ***CAUSTIC SODA.*** Technical data sheet on caustic soda available from The Dow Chemical Co. Covers manufacture, chemical and physical properties, storage and handling methods, first aid for caustic burns, etc.

83 • ***HOSE AND BELTING.*** Quaker Rubber Corp. hose, belting, and sheet packing described in loose-leaf bulletin. Sizes, uses, dimensions, etc., detailed.

84 • ***FIBERGLASS TANKS.*** Models of fiberglass tanks and trucks for use in textile, dyeing, chemical, foodstuff, and other industries illustrated in loose-leaf pages from Laminex Corp. Physical properties, chemical resistances, economic advantages given.

85 • ***MANOMETERS.*** A manual on manometers from King Engineering Corp. includes basic facts and definitions, operating principles, how to measure, installation, and operating procedures, tables, temperature correction factors, construction details, etc.

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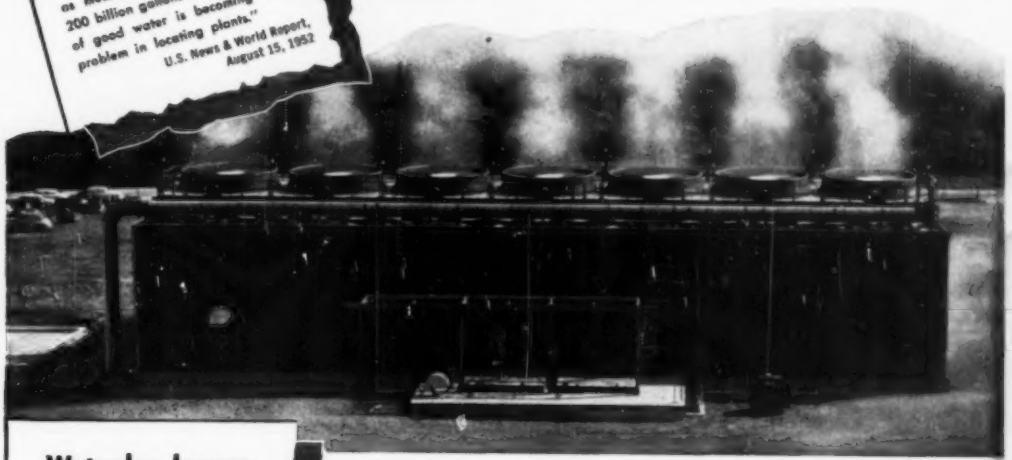
U.S. News & World Report, August 15, 1952



Water has become a problem...

"Even water, once regarded as a 'free commodity' of virtually unlimited supply, has become a problem. . . . The essence of the . . . problem is costs."

Fortune, August, 1952

Industry will spend about $10 billion more...

"The waste of our civilization threatens one of our vital resources: water. . . . It is estimated that . . . U.S. industries will probably have to spend about $10 billion more . . ." (to handle waste water in the next 20 years).

Scientific American, March, 1952

In 1975, according to reliable estimates, American industry will require 2½ times as much water as it does today. It follows that the ability of your present cooling equipment to conserve water will be of much greater value tomorrow when water is twice as scarce. Provided, of course, that the cooling towers you buy now are still operating in 1975.

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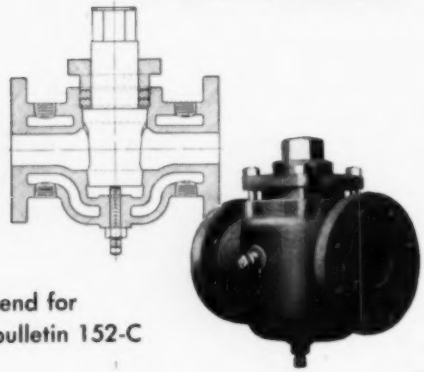

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CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before December 15, 1952, at the Office of the Secretary, A.I.Ch.E., 120 East 41st, New York 17.

APPLICANTS FOR ACTIVE MEMBERSHIP

Allen, G. F., *Midland, Mich.*
Axelson, John W., *North Plainfield, N. J.*
Bednars, Charles, *Port Washington, N. Y.*
Brown, R. F., *Kansas City, Kan.*
Bruce, James S., *Rochester, N. Y.*
Carey, J. Warren, *Wilmington, Del.*
Cody, Nicholas F., *Charleston, W. Va.*
Dance, Eldred L., *Pittsburg, Calif.*
Davis, Trevor C. M., *Huntsville, Ala.*
Dege, August W., *Paramus, N. J.*
Earle, Paul L., *Martinsville, N. J.*
Englehart, Ned H., *Chicago, Ill.*
Hawkins, Harold M., *Bartlesville, Okla.*
Henkel, H. O., *Victoria, Tex.*
Kirk, Norman, *Schenectady, N. Y.*
Massey, R. G., *Charleston, W. Va.*
Mortlock, David H., *New York, N. Y.*
Nixon, Joseph R., Jr., *Wilmington, Del.*
O'Flaherty, Lloyd J., *Akron, Ohio*
Oliver, Eugene H., *Baytown, Tex.*
Osborn, Wm. E., *Springfield, Pa.*
Powell, R. G., *Texas City, Tex.*
Richards, J. C., Jr., *Solon, Ohio*
Rogers, Frank K., *Montreal, P. Q., Canada*
Russell, Harold G., *Bahrien, Persian Gulf*
Sanders, John H., *New York, N. Y.*
Sibley, Robert S., *St. Louis, Mo.*
Smith, William N., *Freeport, Tex.*
Tolman, Charles P., *Kew Gardens, N. Y.*
Warsing, Lewis F., *Lake Jackson, Tex.*
Webb, George B., *Westfield, N. J.*
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Bartel, Edward J., *Wilmington, Del.*
Bass, Max, *Claymont, Del.*
Beers, W. Douglas, *Cincinnati, Ohio*
Bowden, Warren W., *Terre Haute, Ind.*
Bro, Per, *Columbus, Ohio*
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Buiten, William I., *Bellflower, Calif.*
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Cancila, Joseph, *Phila., Pa.*
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Chambers, Robert W., *Kingsport, Tenn.*
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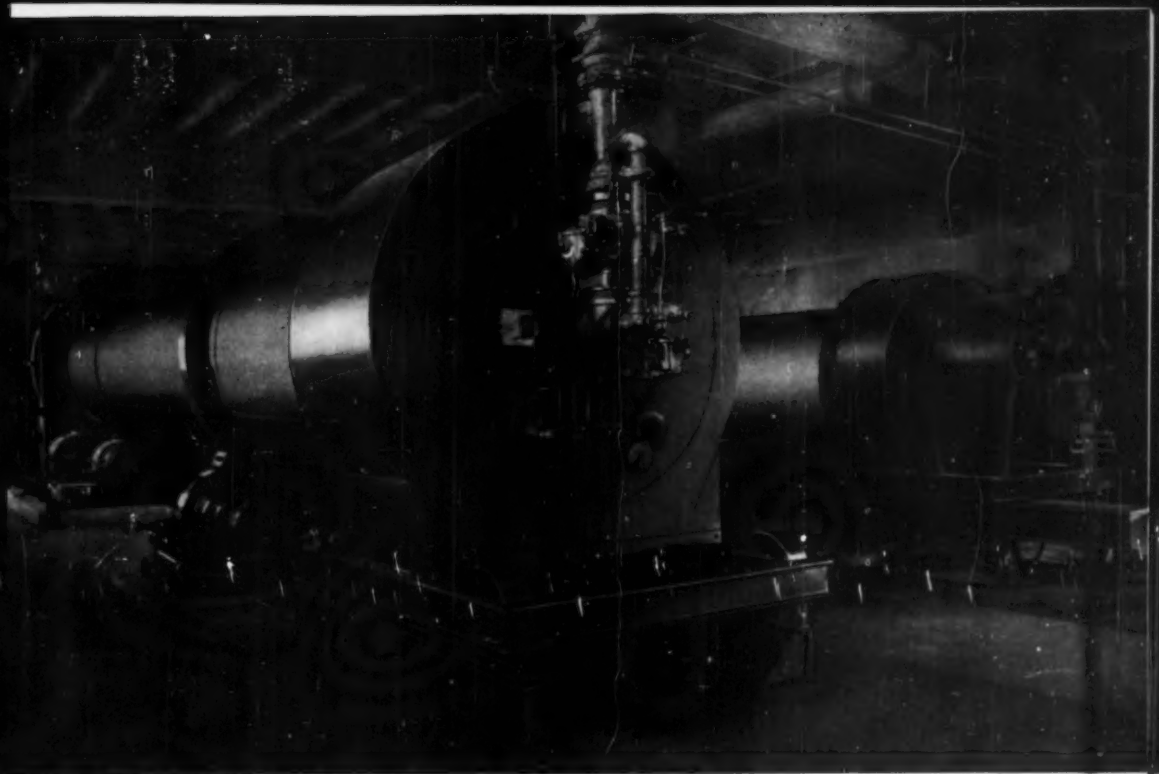
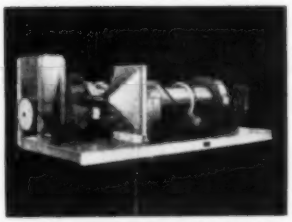
Chou, Adam, *Charleston, W. Va.*
Cochrane, Thomas J., Jr., *Rahway, N. J.*
Covert, Harold Louis, *Ecorse, Mich.*
Creath, Donald B., *Wilmington, Del.*
DeBeck, G. Sanford, *Whiting, Ind.*
DeCarli, Harold F., *New Albany, Ind.*
DeCarlo, Victor A., *Oak Ridge, Tenn.*
Denny, Donald F., *St. Davids, Pa.*
Doubt, Cecil J., *Niagara Falls, N. Y.*
Fairlie, Andrew M., Jr., *Lorain, Ohio*
Fender, Eldon E., *Borger, Tex.*
Ferrall, William L., *New York, N. Y.*

(Continued on page 58)



direct fired Rotary Kilns

for high temperature processing



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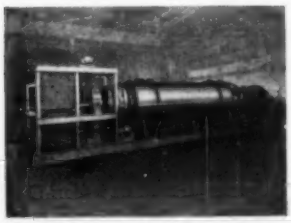

Calciner and Cooler for Continuous Processing at Temperatures from 900° F to 2100° F.

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The new chemical engineering addition to the H. Fletcher Brown Laboratory at the University of Delaware, Newark, was dedicated last month at ceremonies at which the A.I.Ch.E. was well represented. Members from outside the university included W. I. Burt, President; William Chalfant, president of the Philadelphia-Wilmington Section; and Richard H. Wilhelm, 1951 recipient of the A.I.Ch.E. William H. Walker Award. The new building testifies to the rapid expansion of chemical engineering curricula in the nation's universities during the past few decades.

CORROSION COURSE AT BERKELEY

A five-day short course in corrosion will be held Feb. 2-6, 1953, at the University of California, Berkeley. The course is given by the university's extension department and the departments of mechanical engineering, mineral technology and chemical engineering in cooperation with the National Association of Corrosion Engineers.

Speakers from industrial and governmental laboratories and academic institutions will cover basic corrosion-science theory and application of corrosion-mitigation measures. Discussions will cover construction materials, coatings, environment, cathodic protection, corrosion-testing and evaluation, equipment design, high-temperature oxidation and the role of the corrosion engineer in industry.

PHYSICAL CHEMISTRY MEETING PLANNED

Physical chemistry, the chemistry of wood and wood constituents, and macromolecules will be the topics of the XIII International Congress of Pure and Applied Chemistry to be held in Stockholm and Uppsala, Sweden, from July 29 to August 7, 1953, in conjunction with the XVII Conference of the International Union of Pure and Applied Chemistry.

Chemical thermodynamics and thermochemistry, surface and colloid chemistry, chemical kinetics, and other fields will be covered in the section on physical chemistry.

The symposium on wood will be divided into three groups: the structural chemistry of wood components, the chemistry of cellulose, hemicellulose, and pulps, and the chemistry of lignin.

Experimental methods for investigation of macromolecules in solution and macromolecular properties of proteins and polyelectrolytes will compose a second symposium.

Anyone interested in reading a brief paper at the Congress or in attending the various meetings should communicate with the Congress at Stockholm.

QUESTIONNAIRE ON LIBRARIES PLANNED

An inquiry into the habits of engineers in using the engineering library is being planned by the Engineering Literature Project of the American Society for Engineering Education to determine what the practicing engineers think of the value of literature searching and whether they consider a library is important. The society plans to send out late in November a number of questionnaires to engineers, asking the opinions of men in the field on (a) what value they place on library or literature know how; (b) what training they have had in this direction; (c) whether they think such training is desirable or even essential for the prospective engineer; (d) what ideas they have on the sort of training that should be given.

The project of the A.S.E.E. stems from the fact that the educators are convinced that many engineers do not extract full value from engineering literature. Since the engineering library, they reason, is one of the most expensive laboratory units maintained by industrial or educational organizations, some information on the efficiency with which a library is used by engineers seemed to be in order.

Those who wish to answer questions on the subject and who do not receive a questionnaire from the society, may obtain one by addressing Engineering Literature Project, A.S.E.E.X., c/o Edward A. Chapman, Rensselaer Polytechnic Institute, Troy, N. Y.

JEFFERIES ENGINEERING CHANGES ITS NAME

Jefferies Engineering Co., Westfield, N. J., has changed its name to Engineering Corporation of America. The Corporation specializes in the designing and building of special mechanical and process equipment for the chemical and petrochemical process industries.

ENGINEERING ENROLLMENT

A compilation of enrollments in the ten largest engineering schools in the United States was recently made by the Illinois Institute of Technology from data supplied by A.S.E.E.:

TEN LARGEST ENGINEERING COLLEGE ENROLLMENTS, OCTOBER, 1951

	Undergraduate				
	Day	Evening and special	Total	Graduate	Total
1. Illinois Institute of Technology	1376	3765	5141	562	5703
2. Brooklyn Polytechnic Institute	1156	2224	3380	1649	5029
3. Purdue University	3721	13	3734	374	4111
4. University of Illinois	3102	0	3102	406	3508
5. New York University	1176	1256	2432	921	3353
6. College of the City of New York	2151	875	3026	231	3257
7. Massachusetts Institute of Technology	2359	0	2359	810	3169
8. Rensselaer Polytechnic Institute	2585	217	2802	326	3128
9. Georgia Institute of Technology	2804	0	2804	146	2950
10. Pennsylvania State College	2530	19	2549	79	2628

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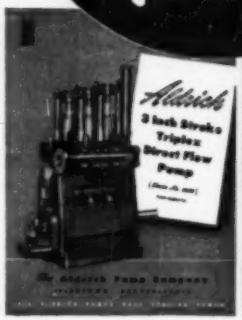

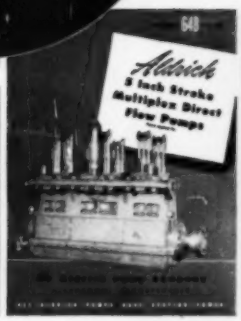

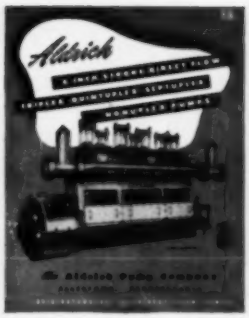

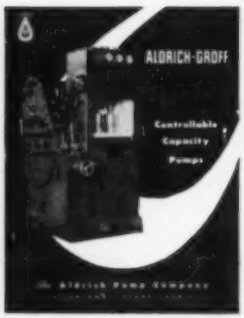

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SECRETARY'S REPORT

S. L. TYLER

THE Executive Committee met at The Chemists' Club Oct. 17. It approved the Minutes of the Executive Committee meeting of Sept. 11, also the Treasurer's report for the month of September and the bills for the month.

All those whose names were listed in the September issue of "C.E.P." were elected to the grades of membership as indicated. Fifteen Student members were elected upon recommendation of the Committee on Admissions. Report of the Tellers Committee on the Nominating Ballot for Officers for 1953 and Directors for a three-year term beginning Jan. 1, 1953, was received and election ballot approved for mailing in October.

R. A. Arnold, Marshall Dick and F. A. Verser, Jr., were placed on the Suspense List because of having entered the Armed Forces. G. M. Blouin, V. R. Bonnette, Jr., J. E. Rothfleisch, R. Sanchez, Jr., and M. A. Vogel were returned to membership status because of their discharge from the Armed Forces. Six elections to Junior membership were rescinded either because no reply was received from the applicant, or acceptance of the election was declined. Four resignations from membership were accepted.

Upon recommendation of the chairman of the Student Chapters Committee, K. F. Gordon was appointed counselor at the University of California to succeed F. C. Williams, J. S. Walton at Oregon State College to succeed J. G. Knudsen, A. Ralph Thompson at the University of Rhode Island to succeed J. M. Woods, S. G. Bankoff at Rose Polytechnic Institute to succeed C. E. Kircher, and H. C. Ries at Tufts College to succeed C. F. Gurnham.

Several committee appointments and replacements were made in the Membership and Public Relations Committee, for the balance of 1952, at which time new committees will be appointed.

The questionnaire prepared by the Public Relations Committee to be sent to all members of the Institute received the final review and was approved for mailing at as early a date as possible.

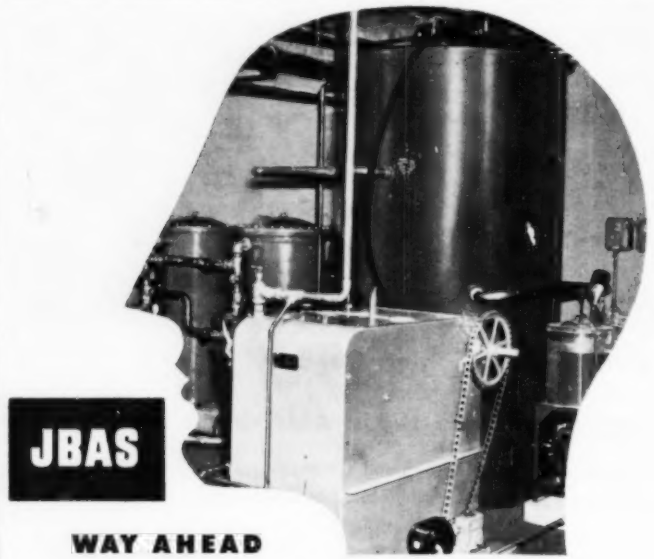
A.I.CH.E. STANDARD FOR HEAT EXCHANGERS

A report on the proper technique of heat exchangers, written by the Committee on Equipment Testing Procedures of the American Institute of Chemical Engineers, has been completed and is now available. The standard which sells for 25 cents to members—50 cents to nonmembers—is available from the Secretary's office at 120 E. 41st Street, New York 17, N. Y. This is the first of a number of publications on chemical engineering equipment and covers "Sensible Heat Transfer in Shell- and Tube-Type Equipment."

The A.I.Ch.E. committee headed by W. T. Dixon, general chairman, turned over the development of the standard to a subcommittee on heat exchangers, consisting of P. V. Bitzer, of the Ross Heater & Mfg. Co., as chairman; W. C. Beckley, vice-president, Whitlock Mfg. Co.; C. F. Bonilla, Columbia University; C. H. Brooks, of Sun Oil Co.; S. A. Guerrieri, University of Delaware; A. C. Mueller, Du Pont Co.; P. S. Otten, Griscom-Russell Co.

The new publication is part of a drive by the A.I.Ch.E. to create methods for rating equipment used by chemical engineers in their industrial work. Others in preparation are on evaporators, agi-

(Continued on page 59)



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NEWS

(*Continued from page 54*)

SINCLAIR CHEMICALS RECENTLY ORGANIZED

To expand its operations in the field of petrochemicals, Sinclair Oil Corp. has organized Sinclair Chemicals, Inc., as a subsidiary of the parent company.

The new organization will take over the production and sales of chemicals recoverable from petroleum raw materials heretofore handled by the petrochemical division of Sinclair Refining Co. Through this department, Sinclair has been promoting hydrocarbons, special solvents, chemical polymers, petroleum sulfonates, and other chemical by-products of the refining process.

"Further expansion in the field of petrochemicals is a natural and logical step for us at this time," P. C. Spencer, president of Sinclair Oil Corp., said. "By converting both light and heavy fractions which heretofore have been sold largely as fuels into chemical products for which there is a growing demand, we not only will be up-grading our sales but, of equal importance, further diversifying our company operations."

The new subsidiary, of which Mr. Spencer also will be president, will utilize the research facilities of Sinclair Research Laboratories, Inc., but will also have its own research staff and market development department, the announcement said.

John A. Scott, manager of the petrochemical division since its inception, is executive vice-president of the new company. E. W. Isom, chairman of the board of Sinclair Research Laboratories, Inc., and director of Sinclair research for more than thirty-five years, will be chairman. Headquarters of the new company will be 600 Fifth Avenue, New York.

REFRESHER COURSE AT DREXEL INSTITUTE

A refresher course in chemical engineering is planned as part of the spring evening curriculum offered by Drexel Institute, Philadelphia, Pa., as preparation for the Pennsylvania state license examination for professional engineers. Courses are also offered in civil, electrical, and mechanical engineering.

The curriculum consists of a twenty-week course devoted to the specific engineering field elected. Problems such as have appeared on previous state examinations will be considered and solutions discussed. A preparatory ten-week basic course in mathematics, physics, and chemistry designed for engineers who have been out of college for some time is being offered this fall.

(*More News on page 59*)

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2. **Phase-Equilibria—Pittsburgh and Houston**
   (138 pages; $3.75 to members, $4.75 to nonmembers)
3. **Phase-Equilibria—Minneapolis and Columbus**
   (122 pages; $3.75 to members, $4.75 to nonmembers)

MONOGRAPH SERIES (8½ by 11, paper covered)

1. **Reaction Kinetics by Olaf A. Hougen**
   (74 pages; $2.25 to members, $3.00 to nonmembers)

Price of each volume depends on number printed. Series subscriptions, which allow a 10% discount, make possible larger runs and consequently lower prices. Discount applies to all volumes in both series published in 1952 and subsequent years.

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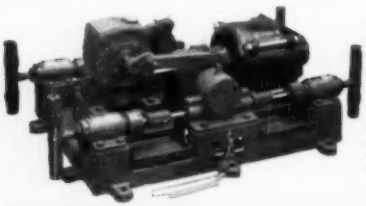

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A.I.Ch.E. STANDARD

(*Continued from page 56*)

tators, pumps, absorbers, dryers, and distillation equipment.

The 12-page standard covers methods of conducting and interpreting performance tests on shell- and tube-type heat-transfer equipment for comparison with the manufacturer's predicted performance. In the introduction to the study, the committee states also that the additional purposes of the standards are for comparison predictions from theoretical heat-transfer equations with commercial performance; comparison of results of theoretical pressure-drop calculations, and accumulation of data on fouling resistances.

The contents of the brochure cover methods of measuring over-all error; measurement of temperature and sources of errors; measurement of flow rates; a determination of fouling resistance and degree of fouling; a method of cleaning heat exchangers, and a final section on the interpretation of test result studies.

SAFETY RECORD BETTER IN CHEMICAL FIELD

The safety record of the chemical industry showed a 10 per cent improvement for the first seven months of 1952 compared with the like period of 1951, according to figures released by the Manufacturing Chemists' Association, Inc. The accident rate for the industry, the Association notes, continues to be well below that for industry as a whole.

Measured in disabling injuries per million man-hours, accident frequency in the chemical industry stood at 4.13 for January through August, 1952, as against 4.61 for the comparable 1951 period. Accident severity, in days lost per thousand man-hours, was 0.78 for 1952, 0.66 for 1951.

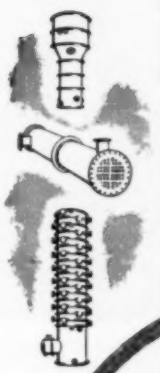
Both of these figures are substantially under the 1951 rates for all industry of 10.06 for frequency and 0.97 for severity.

The M.C.A. data are based on reports from eighty-eight major companies.

A.C.S. WILL PUBLISH NEW JOURNAL

The American Chemical Society has announced plans for a new journal which will be called Agricultural And Food Chemistry, according to Charles Allen Thomas, chairman of the Society's board of directors.

Walter J. Murphy, of Washington, D. C., has been named editor and the journal will make its first appearance in April, 1953. James M. Crowe, executive editor of the A.C.S. publications, will be executive editor of the new journal, and Richard L. Kenyon will be managing editor.



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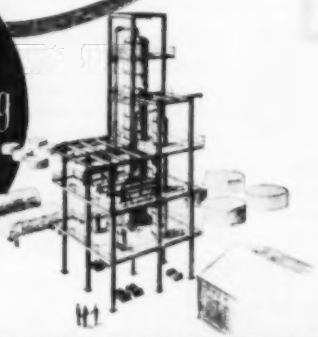
Why not call on our design and manufacturing facilities? We have the experienced engineers, skilled workmen, and fully equipped shops. As for experience, designing and fabricating process equipment is the very kind of work our men have been doing for years. They understand the need for and can provide the advanced techniques and superior workmanship called for to properly meet today's design requirements in process equipment.

If you will send in details of your problem, we shall be glad to present our solution and recommendations.

Engineering and Manufacturing

Process Units

Process Equipment



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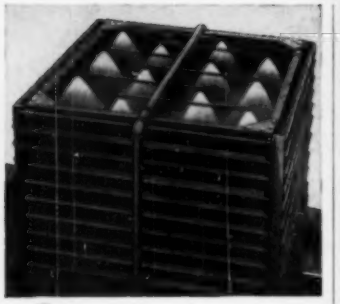

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Left: "Yellow cake" is being scraped off the filter presses. It will then be dried, and packed in steel drums for delivery to A.E.C. Right: A mill employee, standing inside one of the washing tanks, is shovelling vanadium "red cake" into a bucket.

URANIUM EXTRACTED FROM HIGH-LIME ORES

A NEW process for treating high-lime uranium ores was placed in operation during October at the Uravan, Colo., mill of United States Vanadium Co. Walter E. Remmers, president of this division of Union Carbide and Carbon Corp., announced that the Uravan mill has doubled capacity as a result of an expansion program started last year. It is the largest of the nation's uranium ore-treatment plants.

The process at Uravan is believed to be the most efficient process yet developed for the recovery of both uranium and vanadium, which are the two principal minerals found in the carnotite ores of the Colorado Plateau area. Although high-lime ores are fairly abundant in this region, they have never been mined to any great extent because the presence of lime increases the difficulty and cost of extracting the uranium and vanadium. With the new installations, however, it is believed that the problems previously encountered in processing these ores will be overcome.

There are now eight mills in the Colorado Plateau area processing uranium ores, and two new mills are under construction. The new facilities at Uravan will provide additional capacity equal to, and in some cases larger than, that of any other mills in the plateau. Expansion there has involved the erection of a number of thickening and solution tanks of about 40,000-gal. capacity; new roasters several stories high; additional filtering equipment; and enlargement of the sampling plant.

The Uravan mill extracts two products from the ore: uranium and vanadium. There may be as little as one-tenth of one per cent of uranium in the ore, or about an average of two or three parts per thousand. The first step is to add chemical reagents, such as salt, and the ore is fed into roasters, several stories high. After the roasting operation, it is treated in wooden leaching tanks. During this leaching, the uranium and the vanadium are dissolved by different solutions; each mineral is then precipitated by still further processing operations.

Finally, the uranium concentrate is filtered and dried—ending up a bright canary yellow in color. The vanadium concentrate is red.

It is estimated that more than $30 million a year is currently being spent for the mining and refining of uranium ores in the Colorado Plateau, and almost 5,000 people are now taking part in this phase of the atomic energy program. Development of the area has advanced to the point where the plateau is now the second largest source of uranium in the world, and our chief domestic source. The plateau, itself, takes in an area of some 65,000 square miles, and reaches into four states: Colorado, Utah, New Mexico, and Arizona.

The organized prospecting and exploration work done by the mining companies and Government agencies in the Colorado Plateau is said to surpass in scope of operations any similar mineral search in the history of the world. Private companies alone are spending more than $3 million a year on drilling. Altogether, the plateau area has considerably more than 200 uranium mines in operation.

In addition to the Uravan mill, the Vanadium company owns and operates an ore-processing plant at Rifle, Colo., and sampling plant at Thompson, Utah.

(*More News on page* 64)

from CLARIFICATION OF PANCREAS EXTRACT

to PURIFICATION OF BENZENE HEXACHLORIDE

to RECOVERY OF MEAL FROM FISH LIQUOR

to REMOVAL OF SALT FROM CONCENTRATED CAUSTIC SODA

to DEWATERING OF CRUDE LACTOSE

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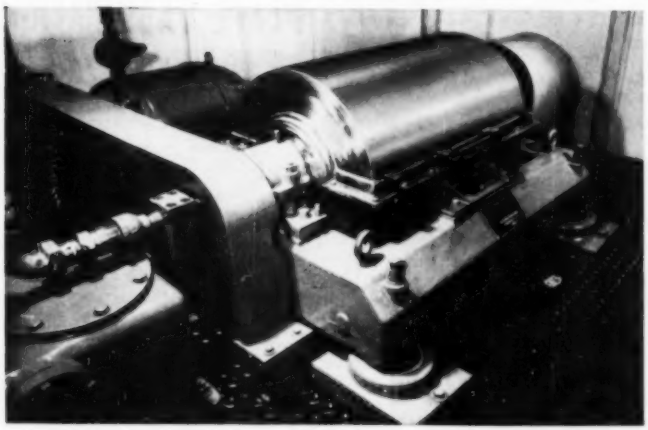
The Super-D-Canter handles slurries and suspensions of practically any consistency—from 1% solids to relatively thick sludges—with solid particles from ½ inch in size down to extremely small particles.

Solids are continuously moved through the Super-D-Canter by means of a helical conveyor, while under high centrifugal force (2100 x g). The clarified liquid continuously overflows adjustable weirs.

For solids which pack tightly and have a high angle of repose, a conical rotating bowl is provided; for relatively soft solids with low angle of repose, a cylindrical rotating bowl is available.

The Sharples Super-D-Canter is a production tool of the process industries that pays big dividends. It would pay you to write for a copy of Sharples Bulletin 1254 which gives complete details on the Super-D-Canter.



The Super-D-Canter in insulin production.

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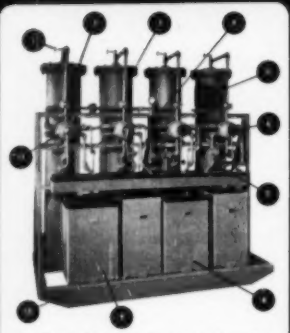

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MARGINAL NOTES

(*Continued from page 44*)

For Beginners and Initiated

Corrosion Testing Procedures. F. A. Champion. John Wiley & Sons, Inc., New York (1952). 369 pp. $6.25.

Reviewed by E. A. Tice, International Nickel Co., Inc., New York.

As the title indicates, this book deals with the many factors which must be considered in conducting corrosion tests. Whether the investigator is concerned with fundamental corrosion research or with practical problems associated with the use of metals and alloys either bare or coated, he will find the contents considerably helpful.

It would appear that the author has been thorough in searching the literature for he has reviewed the works of some 600 or more authors. Thus the reader is made aware of the many procedures and methods which have been employed in corrosion testing and can choose those most useful to him.

The text has been divided into logical stages, each of which is covered in detail. In his introduction, the author enumerates the many purposes for conducting corrosion tests, and the limitations of such testing due to the numerous factors which play a part in the course of corrosion processes. The text then deals with the factors to be considered in selecting and preparing metal specimens; the characteristics of corrosive media; laboratory and field-testing conditions; combined action of movement or stress and a corrosive medium; the cleaning of specimens after exposure; methods of evaluation of the effects on the metal, and on the environment; auxiliary observations such as potential measurements, stray currents, and film thickness measurements; means of expressing and interpreting results, and special tests for specific alloys.

The author has been impartial in describing the many laboratory, field and service test methods, pointing out the advantages and disadvantages of each where possible. The work is replete with illustrations and sketches.

This book should prove most helpful to those workers who are just being initiated into the field of corrosion test work, but it may also be a useful reference to those well acquainted with this field. It is probably the most complete single treatise on the subject, but much of the same material is found in the section, *Corrosion Testing*, contained in Uhlig's "Corrosion Handbook." It is this reviewer's opinion that the purchase of this book might be considered a luxury for those who already own the "Corrosion Handbook," but a worth-while investment for those who do not.

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Diffusion Monograph

Diffusion in Solids, Liquids, Gases. W. Jost. Academic Press, Inc., New York (1952). 558 pp. $12.00.

Reviewed by E. L. Piret, Prof. Chem. Eng., University of Minnesota, Minneapolis, Minn.

WHILE written primarily from the viewpoint of an experimentally inclined physical chemist, there is much in this monograph which is of interest to chemical engineers. It should be a useful reference particularly to those concerned with accelerating the development of the fundamentals of the basic diffusion processes into what is becoming known as chemical engineering science.

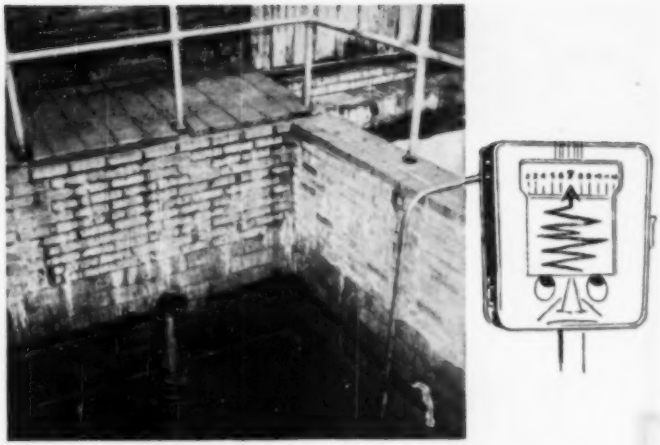
More emphasis is placed on the detailed presentation of selected examples than on completeness in either the theoretical or experimental material. A lucid presentation is made of the theories and of the important equations applicable to a variety of physical and chemical processes in which diffusion is important. Some equations are also included considering the influence on diffusion processes of convection, sedimentation, and chemical reaction. In addition, there are hitherto unavailable integrals for diffusion in two-phase systems.

This reference book is concerned primarily with diffusion in solids, and other than giving a collection of theoretical formulas for practical applications and describing the experimental methods, no attempt is made to present the theory of gaseous- or liquid-diffusion processes in detail.

There is an interesting chapter on order-disorder phenomena in crystal lattices and on their activation-energy relations to those of diffusion and electrolytic conduction. Much attention is given to experiments on electrolytic conduction in solids and with good reason, since conduction is analogous to diffusion.

Since there cannot be any diffusion without a preceding solution, the theory of solubility of gases in metals, zeolites, elastomers and crystals is discussed. The section on transport by permeability through these materials is, of course, also, of practical interest.

Rates of oxidation, protective film formation, and other surface reactions with metals are often controlled by diffusion reactions, and their mechanisms are dealt with at some length. These mechanisms are typical also of a large group of reactions in solids and powders. As is becoming accepted practice, thermal diffusion is treated with the aid of Onsager's reciprocity relations and the concepts of the thermodynamics of irreversible processes.



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for your corrosion-proof mortar

If you are the process engineer in a typical chemical unit, facing alternate acid-then-alkaline conditions, then you want to know how best to handle *both* in corrosion-proof equipment.

The answer is Pennsalt Furan Cement mortar, according to many other plants who have this same problem. Matter of fact, we use it ourselves in our own plants which make everything from household lye to elemental fluorine. And here's why Pennsalt Furan Cement gets the nod:

- Resistant to alkalies, most acids, solvents, greases, organics, salts ...to temperatures of 350-375°F.
- Forms dense, hard, non-porous mortar with excellent abrasion resistance and adhesion.
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- Non-toxic, not conducive to dermatitis, not a fire hazard. Contains no vaporizing solvent.

As you know, users of Pennsalt Cements gain the added benefit of Pennsalt's Corrosioneering Service—built around many years of hard-bitten experience in applying corrosion-proof materials in severe chemical environments. Why not write and find out how Pennsalt Furan Cement may answer a corrosion problem of yours? Corrosion Engineering Products Dept., Pennsylvania Salt Manufacturing Co., Philadelphia 7, Pa.

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long life.

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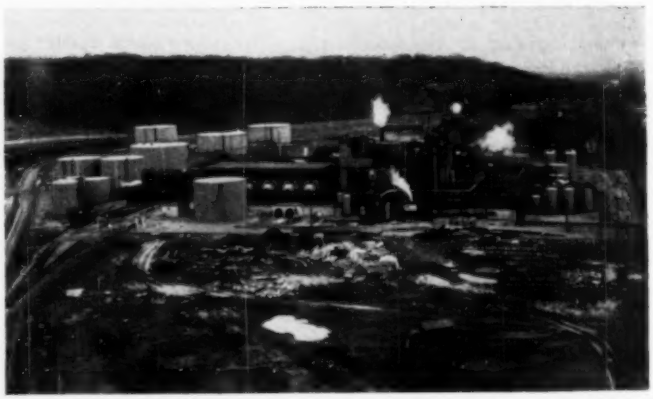
A summary report on the second U.P.A.D.I. (Pan American Union of Engineering Societies) convention held in New Orleans, Aug. 25-30, 1952, reveals that the convention's registration totaled 314. Delegations were present from Argentina, Brazil, Canada, Chile, Colombia, Cuba, Dominican Republic, Mexico, Panama, Paraguay, Peru, Puerto Rico, Uruguay and the United States. The host societies were the Engineers Joint Council, the Engineering Institute of Canada, and the Louisiana Engineering Society. Towards carrying out its aim of encouraging and coordinating the activities of engineers throughout the American Continent, the convention adopted a constitution and bylaws, and a code of ethics for the organization.

Among the members of the U. S. delegation, pictured above, were W. I. Burt, President of A.I.Ch.E. (fourth from the right in the second row) and Stephen L. Tyler, Secretary of A.I.Ch.E. (second from the right in the first row).

Another meeting of the U.P.A.D.I. is scheduled for 1955 in Sao Paulo.



A new phenol plant having a capacity of sixty million pounds a year has been completed at Marietta, Ohio, by Bakelite Co., a division of Union Carbide and Carbon Corp. As shown above, the new unit is an outdoor-type plant with processing equipment erected around a single control building from which the chemical reactions are directed. The phenol is produced by a continuous process from benzene in two main stages. In the first, monochlorbenzene is formed by the reaction of benzene, hydrochloric acid, and oxygen in converters. Only a portion of the materials is converted to the desired product in each stage, so both the intermediate and final products must be processed in separation and refining equipment. The monochlorbenzene is then hydrolized with steam from superheaters and converted to phenol in the second-stage conversion system. The phenol is separated and purified in a separation column and caustic scrubber before it is ready for use. Tanks of 1½ million gallon capacity each store benzene shipped to the plant in tank cars and Ohio River barges.

VULCAN ACQUIRES UREA PROCESS

Vulcan Engineering Division, Cincinnati, has acquired exclusive American and Canadian rights for the building of plants for the production of synthetic urea by the Swiss Inventa process.

Commercial scale manufacture of urea by the Inventa process has been carried on in Switzerland since early 1949, with crystalline urea of plastics and pharmaceutical grade as the product. The Inventa process can be operated with a complete recycle of unreacted carbamate or as a straight once-through process. Corrosion problems have been substantially eliminated in the process.

Vulcan has also acquired American and Canadian rights to Inventa processes for producing synthetic methanol and ammonia and formaldehyde.

The Inventa processes were developed by Inventa's affiliated company, Holzverzuckerungs A. G. (Hovag) of Ems, Switzerland.

URANIUM RECOVERED FROM PHOSPHATE ROCK

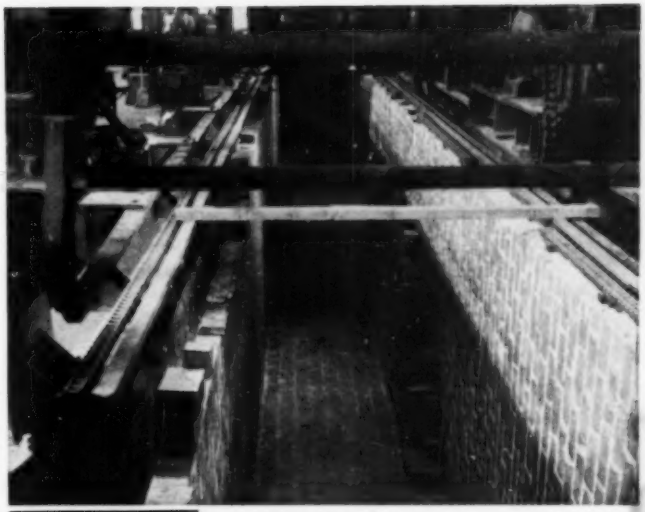
The first commercial unit for the recovery of uranium from phosphate rock has begun operation as a part of the plant of the Blockson Chemical Co. near Joliet, Ill., the U. S. Atomic Energy Commission announced recently.

Research, engineering and construction of the unit were accomplished by the Blockson Chemical Co., which has a contract to supply the recovered uranium to the A.E.C.

Uranium occurs as a very minor component of the extensive phosphate deposits of Florida and several Western states. Studies sponsored by the A.E.C. have established the feasibility of recovering these small quantities of uranium as part of the process of manufacturing sodium phosphate chemicals and concentrated commercial fertilizers.

The uranium recovery facilities will be operated in conjunction with the Blockson company's existing plant for the production of phosphate chemicals near Joliet. Phosphate rock from Florida is used in the plant.

Several other processors of phosphate rock have conducted research and pilot plant studies in the field of uranium recovery, and three companies are building full-scale recovery units. The International Minerals and Chemicals Co. and the Virginia-Carolina Chemical Corp. are incorporating uranium recovery units into plants now under construction near Mulberry, Fla., and the Texas City Chemicals, Inc., is building a recovery unit at Texas City, Tex.



Pickling tank under construction

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When corrosion proof equipment is needed many companies call in Maurice A. Knight as a matter of course. They have two excellent reasons for doing this. First, the Knight organization has been making chemical equipment for over 45 years. Second, each unit of Knight equipment is engineered to the specific job.

Knight equipment includes:

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Permanite (woven glass fibre-reinforced Furan Resin) HCl Absorbers, fume washers, vessels, pipe and fume ducts.

Sealon (vinyl type) tank linings.

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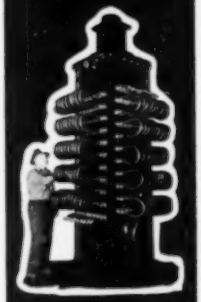
Pyroflex Constructions: pickling and plating tanks, gas cooling towers, chlorine drying towers, acid concentrators, etc. Functional units engineered and constructed to operate satisfactorily under specified service conditions.

Whether you need pilot plant or production equipment, discuss your needs with M. A. Knight. When making inquiry, please specify service conditions.

Literature will be sent on request.

Pipe and Duct Work



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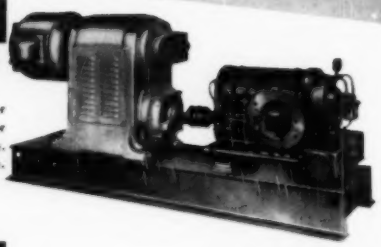
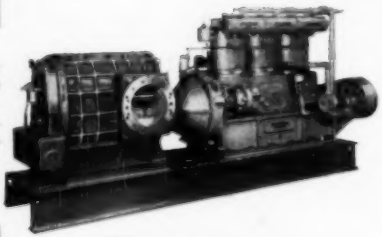


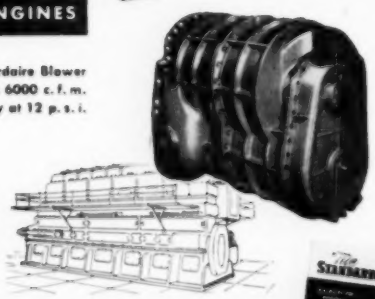
for SEWAGE PLANTS

Standardaire Blower with Climax Engine using sewage gas—to deliver 2100 c. f. m. at 720 r. p. m.



for DIESEL ENGINES

Standardaire Blower with 6000 c. f. m. capacity at 12 p. s. i.



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CHEM. ENGRS. IN RECORD ENROLLMENT AT MONTANA

Montana State College, at Bozeman, reports an increase of nearly 100% in freshman enrollments in the chemical engineering department this fall. This increase is responsible for the fact that the total enrollment in the department is the highest since 1948.

Enrollment figures are as follows, with last year's enrollment shown in parentheses: Freshmen 34 (18), Sophomores 19 (14), Juniors 15 (7), Seniors 8 (6), Graduate 7 (7).

NEW DIFFUSION PLANT FOR A.E.C.

The U. S. Atomic Energy Commission will construct a new gaseous diffusion plant for the production of uranium 235, in Pike County, Ohio, about 22 miles north of Portsmouth, Ohio. About 6,500 acres of land will be acquired. The exact boundaries of the site will be determined after completion of detailed engineering surveys. According to the commission the potential availability of power at reasonable cost and the availability of water were important factors in selecting the site.

Preliminary design calls for a plant estimated to cost about $1,200,000,000. It will require up to 400,000 kw. of power for early operations and new power plants will be built to supply the maximum of 1,800,000 kw. needed when the entire plant is in operation.

Construction of the plant is scheduled to take about four years.

PUBLIC RELATIONS COMMITTEE QUESTIONNAIRE

The Public Relations Committee of the Institute has had in preparation for about a year a questionnaire for submission to Institute members for the purpose of obtaining information which would be of value to the Council and the committees of the Institute. The Council has studied this questionnaire and has now approved a draft.

The hope is that the return of this questionnaire will make information available on opinions of the membership regarding the Institute and its activities, which will help in planning future programs. In addition to this a limited amount of personal information regarding the membership is requested. Space is provided for comments or suggestions beyond the scope of the answers to the questions which are so framed as to allow for machine tabulation.

The questionnaire will be distributed to all members of the Institute and their cooperation is urged in promptly filling out and returning this questionnaire.

ETHYLENE OXIDE BY FLUIDIZATION PROCESS

A new fluidized bed process for the production on a commercial scale of ethylene oxide by direct oxidation of ethylene gas with air was announced last month by Vulcan Engineering Division, as a joint endeavor by Vulcan and the Atlantic Refining Co.

The Atlantic-Vulcan process grows out of research started by the Atlantic Refining Co. in Philadelphia. After developing a unique fluidized catalyst and carrying on extensive bench-scale research, Atlantic postponed further development because of the pressure of other work. Shortly after this Vulcan agreed to take over the process and develop it further in exchange for exclusive rights to design and build plants utilizing the process when its development was complete.

Vulcan has carried on bench-scale work for several years and for the past year has operated a large integrated pilot plant. From data obtained in the pilot plant a process for the production of ethylene oxide was developed, and Vulcan is at present designing an initial plant and estimating operating costs for various-sized large scale units.

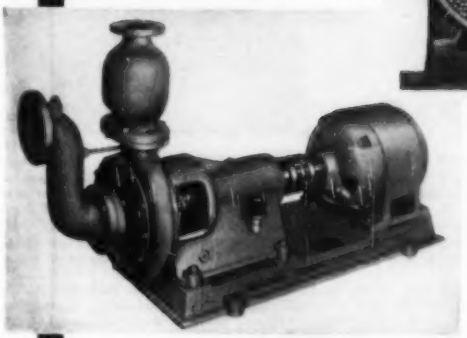
ISOTOPES CHECK CATALYST FLOW

An unusual application of radioactive tracer technique was developed recently at Salt Lake Refining Co.'s Houdriflow Catalytic Cracking unit at Salt Lake City, Utah. In this unit, cracking is accomplished by bringing oil vapors into contact with a solid moving bed of bead catalyst passing downward through the reactor and regenerator. Uniform flow of catalyst is necessary for maximum operating efficiency but, the determination of flow rates of solid particles inside cracking vessels poses a problem.

Engineers of the California Research Corp. conceived the idea of introducing into the unit a few pellets of catalyst impregnated with a radioactive substance. The travel of individual radioactive particles was traced by means of Geiger counters located at appropriate points along the catalytic equipment. The intensity of radiation from the particles was selected at such a value that the path and average velocity of individual radioactive particles could be plotted.

The survey proved that catalyst circulated uniformly; the average velocity of catalyst particles flowing down the main seal leg from lift disengager into reactor was measured repeatedly over a period of several weeks with a maximum deviation from the mean result of less than five per cent.

(Right) Lawrence Self-Priming Pump exhausting air during priming.



(left) Lawrence Heavy Duty Self-Priming Chemical Pump.

LAWRENCE... SELF-PRIMING PUMPS

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The Lawrence self-priming pump introduces a new feature: — specifically, a pump that operates as a positive air pump during priming and then as a regular centrifugal pump. No valves of any kind are required. After priming, it operates — without recirculation of the liquid — at full efficiency.

Because dead spaces are eliminated and clearances are not close, the pump can be used for pumping liquids containing solids and abrasive matter in suspension. It can be furnished in all sizes for all classes of service: — water, slurry, sludge, acids and chemicals.

For further information and performance data, write for Bulletin 210-1.

LAWRENCE PUMPS

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More than 130 people attended the annual state meeting of the Tulsa Section of A.I.Ch.E. held Oct. 11, on the University of Tulsa campus. The program consisted of eight technical papers and a luncheon address. The papers presented dealt with the production of some important raw materials for the manufacture of petrochemicals, and the manufacture of certain chemicals from such petroleum source materials. General chairman was T. P. Cook.

Industrial exhibits were on display at the meeting also. These included a model gasoline plant, Fiberglas (plastic) pipe, a model oxygen plant, chemicals from petroleum and a model of Selas furnace (process heater).

Above is a scene of the head table at the luncheon held in the University Methodist Church dining room. Those shown are, left to right: C. R. Ringham, Phillips Petroleum Co., Bartlesville, Okla.; T. P. Cook, Blaw-Knox Constr. Co., Tulsa, Okla.; Pierce M. Reynolds, Mid-Continent Petroleum Co., Tulsa; M. M. Romer, Blaw-Knox Constr. Co., Tulsa; C. S. Minden, Stanolind Oil and Gas Co., Tulsa; Oakah L. Jones, Oklahoma Natural Gas Co., Tulsa; I. A. Anson, Bell Oil and Gas Co., Tulsa; Glen R. Davis, Stanolind Oil and Gas Co., Tulsa; H. P. Hohenadel, Cities Service Co., Bartlesville; H. S. Wood, Mid-Continent Petroleum Co., Tulsa; George E. Hays and Howard B. Irvin, Phillips Petroleum Co., Bartlesville.

NEW COMBINATION HEAT EXCHANGER

A combination heat exchanger of a glass-lined steel shell, and Karbate impervious graphite tubes, is a recent development of two chemical engineers, both A.I.Ch.E. members, Irving Siller of The Pfaudler Co., and C. E. Ford of National Carbon Co., a division of Union Carbide and Carbon Corp. While the development is applicable to chemical processing equipment in general, it has found its first use in heat exchangers, where glassed steel is necessary for structural strength and impervious graphite for its high thermal conductivity. Another advantage is the resistance they provide to a long list of corrosive substances.

Heat exchangers and condensers made of glass-lined steel and impervious graphite may be constructed in three different ways according to Siller and Ford: a steel shell with glass-lined steel bonnets and impervious graphite-tube-bundle assembly; glass-lined steel shell with unlined bonnets and impervious graphite tubes; or glass-lined steel shell and bonnets with an impervious graphite-tube assembly. The exchangers can be set up as single-pass or multiple-pass systems, with the corrosive fluid flowing either through the tubes or around them.

Manufacturing Process

The construction of such exchangers begins with the steel plate used to form the steel and glassed-steel parts. The plates are cut and rolled and the seams welded on a continuous, automatic submerged arc-welding machine. The joints are butt-welded and then ground to remove the excess bead and to make the weld flush with the parent metal. All required openings are cut and die-punched to form "dimple" or swaged holes to which the necessary nipples and flanges are welded.

After the steel shell or bonnets have been formed, all inside and outside surfaces are sandblasted as a preparation for the coating cycles and external finishing.

The next operation is the application of the glass to all contact surfaces. After the glass coating is applied, the part is fired in a furnace at 1600-1700° F. until the glass fuses. From four to six coats are thus applied, each being about 0.006 in. thick, until a finished enamel shield is attained that is from 0.024 in. to 0.036 in. thick.

The glass frit is compounded by Pfaudler's technicians, and is supplied both to Pfaudler's domestic and foreign plants.

Cobalt is an important ingredient in effecting the chemical-thermal bonding action that takes place and consequently all base coat mixtures contain this element. The well-known blue color code is used as a convenient identification. Other colors are achieved by pigmenting the cover coats. The color pigment used however has no bearing on the chemical characteristics of the coating.

An important accomplishment in the mixing of the glass frit is the control of thermal expansion coefficient. The finished glassed surface, whether one coat or six, has a standard relative coefficient of thermal expansion as compared to steel. In the case of heat exchangers the value of this factor is obvious when either high — or low — heat-operating cycles are considered.

After the shell has been coated, visual inspection is followed by an electrostatic inspection. A high-tension current is passed over the surface; since the current is grounded to the steel shell any break in the coating permits the circuit to be completed and the resulting sparks pin-point the flaw, if any. Should a great number of breaks appear the coating is sandblasted away and the entire process done over. However, if a permissible number of contacts is not exceeded they can be repaired by drilling through the glass and inserting a tantalum plug with a Teflon gasket under it. The steel is given an X-ray inspection, the finished shell is hydrostatically tested and Teflon gaskets fitted to the end heads and connecting flanges to complete Pfaudler's operations.

The finished shells are then sent to National Carbon Co., where Karbate impervious graphite-tube-bundle assemblies are installed.

View of Karbate impervious graphite-tube bundle being assembled in glass-lined steel shell.

MONEY NEEDED FOR ENGINEERING EDUCATION

A warning to educators not to expand courses and programs at the cost of other departments was voiced to the Engineers Council for Professional Development, at its annual meeting in Chicago, in September, by Prof. John Millett of Columbia University, who talked to the group about some of the findings of the Commission on Financing Higher Education, of which he was the director. Professor Millett was particularly pointed in his remarks about the course of medical education in this country, and he termed the cost of educating doctors a disgrace since "it has been financed by the Universities at the expense of other departments, particularly teaching, business administration, engineering and the liberal arts in general." Professor Millett said that while accrediting procedures are good, they might cause a university to sacrifice developments in other departments in order to meet the standards demanded. Millett said further that professional groups who undertake accrediting should concern themselves also with the cost and the financing of the program.

As for the costs of engineering education, Millett said that "they were rising slowly, owing to the fact that courses are becoming more elaborate, students are specializing and requiring a longer training period. There is also an increased cost in engineering education as enrollments increase and as inflationary trends create salary problems in teaching staffs." He added that financial help must come from the Government, from private philanthropies, and from the alumni. "The United States," he continued, "now spends 15 billion dollars a year for public welfare functions, such as old age benefits and aid to dependents, while it is spending only half of that amount on education.

"Another problem that increasing costs are forcing on our colleges is that of keeping desirable professors on the payroll. The intellectual aura of our colleges is being destroyed, as faculties dwindle, and this is one of the most precious assets in student development that we have."

NEW CATALYST PLANT FOR HOUDRY

Houdry Process Corp. placed in operation at Paulsboro, N. J., last month, a plant for the manufacture of Type 3 Catalyst to be used in Houdriforming operations for up-grading naphthas to high octane gasolines, and the production of aromatics. The Paulsboro plant initially will produce new catalyst for Houdriforming plants now under construction having a total capacity of approximately 25,000 bbl./day.

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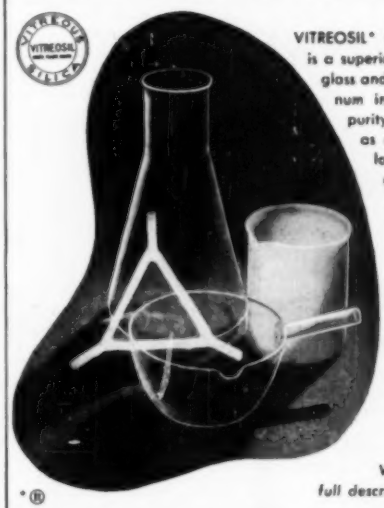

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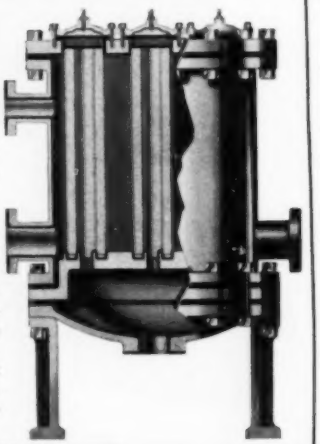

Bulletin 430 shows flow diagrams. Write for a copy.

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LOCAL SECTION

CALENDAR OF MEETINGS

The original listing of scheduled meeting dates of local sections was published in the October issue of "C.E.P.," page 65. The following is supplementary to that list:

Charleston, W. Va. Nov. 18, Jan. 20, 1953, Feb. 17, March 17 and April 21.

Contact: R. D. Bower, Carbide & Carbon Chemicals Co., South Charleston 3, W. Va.

National Capital. Nov. 17, Jan. 19, 1953 and Feb. 12.

Tentatively scheduled: April 20, May 18 and June 22.

Contact: George A. Schwabland, Hunting Towers West, Alexandria, Va. Phone: KIng 8-3805.

Northern California. The third Monday of each month except July and August.

Contact: Charles R. Wilke, University of California, Berkeley 4, Calif. Phone: Ashberry 3-6000, Ext. 592, or E. B. Chiswell, California Research Corp., 576 Standard Avenue, Richmond, Calif. Phone: Beacon 2-1514.

Pittsburgh. Dec. 10, Jan. 14, 1953 (Junior member night), Feb. 4, March (Student night-date to be announced), April 1, and May 6.

Contact: James H. Obey, Mellon Institute, Pittsburgh, Pa., Warren M. Trigg, Westinghouse Electric Corp., East Pittsburgh, Pa., or Hugh H. Kellner, Gulf Research & Development Co., Pittsburgh, Pa.

PITTSBURGH

The first meeting for the year 1952-1953 was held at the Royal York Apartments, Oct. 1. A brief business session was held after the dinner at which the new officers elected in May, 1952, were introduced.

Karl B. Lutz, representing the Pittsburgh Patent Law Association, spoke on "Answering the Chemical Engineer's Questions about Patents."

Mr. Lutz, associated with the Pittsburgh patent attorney firm of Brown, Critchlow, Flick and Peckham, traced the history of the patent system in England and the United States and showed how this system has helped industrial and technological progress. The ultimate result, however, is benefit to the general public from the use of these new products. He likened a patent to a carrot (signifying incentive), an umbrella (signifying protection), a whip (signifying a spur to the competition), and an encyclopedia (signifying the vast store of information in the patent literature).

The speaker closed by outlining some requirements that must be met to obtain a patent.

Reported by J. R. West, H. A. Morrissey, and J. H. Black

(More Local Section on page 72)

FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.

Technical Program Chairman: R. L. Savage, Dept. of Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

Biloxi, Miss., Buena Vista Hotel, Mar. 8-11, 1953.

Technical Program Chairman: Norman A. Spector, Vitro Corp., 233 Broadway, New York 7, N. Y.

Toronto, Canada, Royal-York Hotel, April 26-29, 1953.

Technical Program Chairman: Brymer Williams, Dept. of Chem. and Met. Eng., University of Michigan, Ann Arbor, Mich.

San Francisco, Calif., Fairmont and Mark Hopkins Hotels, Sept. 13-16, 1953.

Technical Program Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Annual—St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.

Technical Program Chairman: R. M. Lawrence, Monsanto Chem. Co., St. Louis 4, Mo.

SYMPOSIA

Applied Thermodynamics
Chairman: W. C. Edmister, California Research Corp., Richmond, Calif.
Meeting—Cleveland, Ohio

Human Relations
Chairman: R. L. Demmerle, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.
Meeting—Cleveland, Ohio.

Modern Statistical Methods in Chemical Engineering
Chairman: C. Daniel, Engineering Statistician, 116 Pinehurst Ave., New York 33, N. Y.
Meeting—Cleveland, Ohio.

Filtration
Chairman: F. M. Tiller, Dir., Div. of Eng., Lamar State College of Technology, Beaumont, Tex.
Meeting—Cleveland, Ohio

High Pressure
Chairman: E. W. Comings, Head, School of Chem. & Met. Eng., Purdue University, Lafayette, Ind.
Meeting—Cleveland, Ohio.

Chemical Engineering in Hydrometallurgy
Chairman: John D. Sullivan, Battelle Memorial Institute, Columbus, Ohio.
Co-Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio.
Meeting—Biloxi, Mississippi

Mineral Engineering Techniques for Chemical Engineers
Chairman: N. Morash, Titanium Div., National Lead Co., P. O. Box 58, South Amboy, N. J.
Co-Chairmen: T. S. Leary, Calco Chem. Div., Bound Brook, N. J., and D. W. Oakley, Metal & Thermit Corp., Carteret, N. J.
Meeting—Biloxi, Miss.

Ion Exchange and Adsorption
Chairman: N. R. Amundson, Dept. of Chem. Eng., Univ. of Minnesota, Minneapolis 14, Minn.
Meeting—San Francisco, Calif.

Mixing
Chairman: J. H. Rushton, Dept. of Chem. Eng., Illinois Inst. of Tech., Chicago, Ill.
Meeting—San Francisco, Calif.

Distillation
Chairman: D. E. Holcomb, Dean of Eng., Texas Technological College, Lubbock, Tex.
Meeting—St. Louis, Mo.

Dust and Mist Collection
Chairman: C. E. Lapple, Dept. of Chem. Eng., Ohio State University, Columbus 10, Ohio.
Meeting—St. Louis, Mo.

Fluid Mechanics
Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Absorption
Chairman: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

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LOCAL SECTION NEWS

(Continued from page 70)

ATLANTA

R. S. Ingols, of Georgia Tech Engineering Experiment Station, spoke before the Nov. 3 dinner meeting at Mammy's Shanty, Atlanta. He discussed "Industrial Water Problems." At the Dec. 1 dinner meeting at Brittain Dining Hall, Georgia Tech, J. G. Dickerson, of Shell Chemical Corp., New York, will discuss "Properties and Applications of Chemicals Synthesized from Petroleum Raw Materials."

Reported by E. H. Conroy

MARYLAND

This Section held its first monthly meeting of the 1952-53 season at the Deutsches Haus, Oct. 14. The meeting was preceded by a dinner. A brief business meeting was held at the dinner, and then the group heard an address by W. C. Schroeder, chief, Office of Synthetic Liquid Fuels, U. S. Department of Interior, Bureau of Mines.

Mr. Schroeder talked about synthetic liquid fuels. In this talk, he discussed developments and history of all three phases of synthetic liquid fuels, including hydrogenation of coal, production of fuel by the Fischer Tropsch process, utilizing coal, and the recovery of crude oil from oil shale. He also showed a 20-minute movie covering the mining of oil shale.

Reported by L. C. Palmer

NORTHEASTERN NEW YORK

The second meeting of the Section was held at R.P.I., Troy, N. Y., Oct. 7. The thirty persons present heard a talk by Professor Beers of the department of fuel resources at Rensselaer Polytechnic Institute. Dr. Beers spoke on the topic "The Total Energy Demand and The Total Energy Reserves of Fuels in the United States." A movie on the engineering problems encountered in drilling a successful well was shown.

A program of a series of lectures to be given by engineers in industry is to be conducted by the Section concurrently with a design course for the R.P.I. chemical engineering seniors as a part of the spring 1953 curricula.

Reported by Roger E. Larson

NATIONAL CAPITAL

H. B. McClure, vice-president, Carbide & Carbon Chemicals Co., addressed this Section, Oct. 6, in the du Pont Room of the du Pont Plaza Hotel. His subject was "Production of Chemicals from Coal Hydrogenation."

Reported by R. H. Moyer

CENTRAL OHIO

A meeting was held Oct. 21 at the Seneca Hotel, Columbus, Ohio. J. W. Salter, chief engineer, The Keever Starch Co., Columbus, gave a talk titled "Wheat Starch Products."

Mr. Salter described the types of starch products manufactured by The Keever Starch Co. and their applications. He also discussed the engineering operations involved in their manufacture and the special equipment used.

Mr. Salter was associated at one time with the National Starch Products Co. in New York City. He was in the Navy for three years and upon being separated he became associated with The Keever Starch Co.

Reported by K. S. Jacobs

WASHINGTON-OREGON

Officers for this Section for the 1952-53 season are as follows:

Chairman—B. B. Butler, The Borden Co., Chemical Division, 6010 Airport Way, Seattle 8, Wash.

Vice-Chairman—N. F. Robertson, West Tacoma Newsprint Co., Box 8, Steilacoom, Wash.

Secretary-Treasurer—R. E. Noble, Hooker Electro Chemical Co., Tacoma, Wash.

Reported by B. B. Butler

NEW ORLEANS

The meeting on Oct. 13 in the Jackson Room, St. Charles Hotel, was the annual joint meeting with the Louisiana Engineering Society. Construction of American Cyanamid's nitrogen products plant in New Orleans was discussed by G. J. Forney, project manager, American Cyanamid Co. and J. W. Hamilton, resident manager, Chemical Construction Co.

Mr. Forney's presentation referred to the American Cyanamid Co.'s entering the basic nitrogen product field, via the natural gas route, involving the manufacture of anhydrous ammonia, hydrocyanic acid and acrylonitrile. Mr. Hamilton's presentation dealt with the required construction organization for this $50,000,000 heavy chemical project.

At the Sept. 9 dinner meeting at the Engineers and Architects Club of New Orleans, twenty-two people heard F. A. del Marmol speak on "The Morphological Method," a new technique for organizing knowledge. Mr. del Marmol was formerly assistant director of guided missiles development, Bureau of Ordnance, Navy Department. A government film showed the preparation and launching of a V-2 rocket.

Reported by Joseph Pominski et al.

CENTRAL VIRGINIA

This Section held a dinner meeting at the Albermarle Hotel, Charlottesville, Va., Oct. 10, 1952. Fifty-four members and guests were present.

Speakers for this meeting were Barclay Morrison of the Carpenter Steel Co., and J. J. Folz of the Horace T. Potts Co. Mr. Morrison spoke on "Corrosion," briefly described the various types and their causes pointing out the type of alloys to use to resist these corrosions. Mr. Folz described some of the newer developments and methods of using corrosion-resistant materials.

Reported by L. E. Poese

NORTHERN CALIFORNIA

The first of the regular dinner meetings of the fall season was held Sept. 15 at the Engineers' Club in San Francisco. At this time, Chairman H. D. Guthrie presented to G. J. Maslack, of the Institute of Engineering Research at the University of California in Berkeley, a certificate of award for the best presentation of a paper at the French Lick meeting of A.I.Ch.E.

The speaker on the program was Charles L. Hamman of the Stanford Research Institute. Mr. Hamman discussed the resources of the Western states, giving particular attention to the water, energy, and forest resources of this region. His remarks were based on information gathered by Stanford Research Institute for use in the preparation of a Western Resources Handbook.

Reported by D. F. Rynning

SOUTHERN CALIFORNIA

The Oct. 21 meeting was held at the Old Dixie Barbecue in Los Angeles with the featured speaker, William F. Abbot, component test department, U. S. Naval Air Missile Test Center, Point Mugu, Calif. Mr. Abbot presented a general talk covering the field of liquid rocket motors. Equipment was exhibited through the cooperation of the Commander of the U. S. Naval Air Missile Test Center.

The September general meeting took place at the aforementioned restaurant on the sixteenth with seventy-five members and guests present. F. G. Sawyer, assistant to director of research, Stanford Research Institute, discussed responsibilities of his Institute.

Reported by Gale S. Peterson

NEW YORK

O. E. Rhodes, of The Koppers Co., will address this Section, Dec. 16, 1952, at noon, at the Brass Rail, Fifth Avenue, New York. The title of his subject is "The Coal Tar Industry—Past, Present and Future."

Reported by R. F. Shaffer

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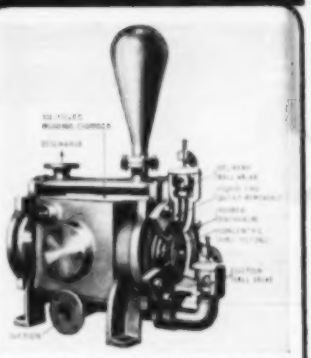

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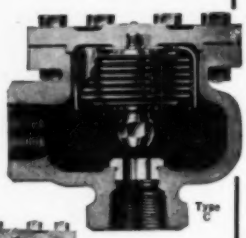
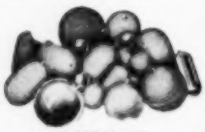
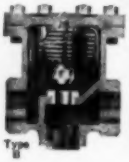
from 65 to 45 Min.

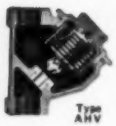
with Nicholson Steam Traps

Records of a recent installation of Nicholson steam traps, by a large processor, show they cut cooking time 30%; e.g., one operation was shortened from 65 to 45 min. Nicholson units keep equipment full of live steam because: 1) they operate on lowest temperature differential; 2) have 2 to 6 times average drainage capacity. Also record low for steam waste; and maximum air-venting capacity. Widely specified for preventing damage to thin gauges; eliminate cold blow in unit heaters.









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ST. LOUIS

A dinner meeting was held Oct. 21 at the York Hotel at which C. E. Ford, assistant manager, industrial carbon department, National Carbon Co., Union Carbide and Carbon Corp., discussed "Recent Developments in Karbate Process Equipment." Mr. Ford received his engineering degrees from Purdue and Harvard Universities, in 1933 and 1934, respectively. He has been associated with National Carbon Co. since 1937.

NASHVILLE

A dinner meeting was held at the Twin Oaks Dinner Club in Columbia, Tenn., Oct. 23, 1952. E. P. Rucker, patent attorney for the phosphate division of the Monsanto Chemical Co., spoke on "Patents as Related to the Chemical Industry."

Mr. Rucker holds a B.S. degree in chemistry and an L.L.B. degree in law.

Reported by J. C. Katz

WESTERN NEW YORK

The establishment of an Annual Professional Achievement Award has been announced by the Executive Committee and directors of this Section. This award will be given each year to an active member of the Section in recognition of his service to the Institute and his contributions to the profession as a whole.

G. N. Harcourt of Buffalo, N. Y., has been selected as the recipient for this year. The Certificate of Award was presented at the Oct. 9 dinner meeting which was called "The Professional Achievement Award Dinner." Mr. Harcourt is vice-president in charge of engineering of the Buflovak Equipment Division of Blaw-Knox Co.

NEW JERSEY

John M. Seabrook, executive vice-president of Seabrook Farms Co., Bridgeton, N. J., spoke before this Section at the University Commons, Rutgers University, New Brunswick, N. J., Oct. 14, 1952. The subject was, "Agricultural Waste Disposal" as related to the giant 50,000-acre vegetable garden in South Jersey where 10,000,000 gal. of water polluted with vegetable scraps, must be disposed of daily during peak periods. Pollution of streams or ground water has been prevented at Seabrook Farms and at other sites through the technique of spray irrigation.

Mr. Seabrook told how water contaminated with agricultural wastes is sprayed into near-by wooded areas. When the operation is properly done, the wastes are successfully and economically

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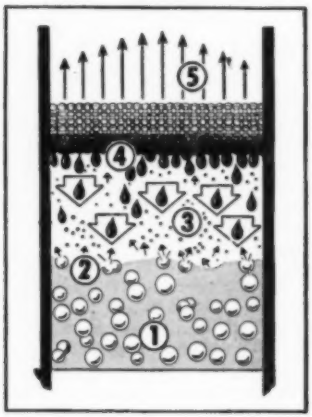
Pads of Knitted Wire Mesh Wipe Out Liquid Entrainment

Removal of the liquid carry-over which is present in a wide range of processing operations is being secured, effectively and economically, by using pads made from multiple layers of knitted wire mesh.

These pads combine, within a few inches of depth, large wire surface area with an unusually high free volume—97 to 98%—made up of a multiplicity of unaligned asymmetrical openings. Installed within a vessel, these pads offer minimum restriction and pressure drop, yet it is impossible for a gas to pass through without continually changing direction and forcing impingement of the entrained liquid droplets upon the wire surface.

How These Pads Work



A gas generated in or passing through a liquid (1), carries with it, as it bursts from the liquid surface (2), a fine spray of liquid droplets. These entrained droplets are carried upward by the rising gas stream (3).

As this gas passes through the pad, the droplets impinge on the extensive wire surface (125 square feet per cubic foot of pad volume). Droplets accumulate on the wire surface and form large drops of liquid which break away (4) from the wire mesh and fall back against the gas stream. The gas (5) passes on, freed from liquid entrainment. The liquid is returned.

Availabiliry

Since these pads, known as METEX MIST ELIMINATORS, can be knitted of practically any metal or alloy available in wire form, effects of corrosion can be minimized. A bulletin giving detailed information is available on request from the manufacturer, Metal Textile Corporation, Roselle, N. J.

disposed of without undesirably affecting the underground water table, flooding the forest floor, or polluting water in near-by wells. Surprisingly, the biological oxygen demand of water in the forest soil underwent a several-fold decrease shortly after the spray irrigation operation was started.

Mr. Seabrook is a licensed Professional Engineer in New Jersey and Delaware.

Reported by L. J. Henry, Jr.

SABINE AREA

The first meeting of the 1952-53 season of this Section was held at Lamar State College of Technology in Beaumont, Tex., Oct. 1, 1952. Approximately seventy-five members and guests showed interest in a panel discussion on "The Chemical Engineer—Active Citizen or Technical Recluse?"

Members of the panel, and their contributions in part were:

F. L. Bryan, assistant chief chemist, Gulf Oil Corp., Port Arthur, Tex.—*Engineers should strive to be good engineers.*

F. K. Mullendore, minister, Trinity Presbyterian Church, Port Neches, Tex.—*More people are unemployed or unemployable because of their inability to work with people than lack of professional ability.*

E. C. Rechtin, general manager, Gulf division, Bethlehem Steel Corp., Beaumont, Tex.—*A person's most valuable asset is his personality, the only thing that is really his.*

F. M. Tiller, director of engineering, Lamar State College of Technology, Beaumont—*Engineering education is subject to pressures in opposing directions.*

A need was voiced for more complete curricula—up to seven years—to provide better professional training plus an adequate basis in the humanities. The discussion was moderated by Clark Barrett, assistant plant manager, Sabine River Works, Du Pont Co., Inc., Orange, Tex.

Reported by H. M. High, Jr.

TWIN CITY

The first meeting of the fall occurred Sept. 24, at the Curtis Hotel in Minneapolis with sixty-four persons present. Fred Lanners, of the Economics Lab. of St. Paul, discussed "Changes in the Minnesota Dairy Industry." He impressed the section with the technological improvements that have been made in sanitation, milk collection, scientific breeding and mechanization. His talk demonstrated the place of the chemical engineer in this field.

Robert Wishart, president of the Hennipen County C.I.O. Council, discussed labor's point of view as Part I in a two-session program on "Labor Relations in the Chemical Industry."

Reported by R. H. Fredrickson

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Three models: Completely Manual—Spring Return to Neutral—Spring Return to Reverse. Flow cycles to handle most requirements.

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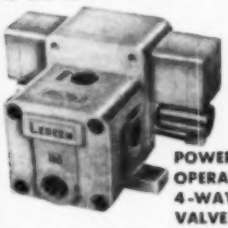
Same as Hand Operated Valve, except foot operation replaces hand. Leaves hands free for other work.



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PEOPLE

Carl F. Prutton has been made president of the Mathieson Development Co., Division of Mathieson Chemical Corp., New York, under a new plan of organization resulting from the expansion and acquisition on October 1 of E. R. Squibb & Sons. All operations, sales and development activities have been placed in four major divisions.

Dr. Prutton became a member of the Case Institute faculty in 1920 and was made head of the department of chemistry and chemical engineering in 1936. He was responsible for the first unit of the new chemical engineering laboratory at Case which was completed in 1939. In 1948 he entered private consulting practice but later in that same year joined Mathieson as director of research. Subsequently he was appointed vice-president-director of operations of all the plants of Mathieson.

The Case Alumni Association gave its Award for Meritorious Service to Dr. Prutton in 1946 for "25 years of inspiring service to the college."

John R. Hallman, formerly a student at the University of Michigan, has accepted employment as a thermodynamic engineer at Consolidated Vultee Aircraft Corp., San Diego, Calif. He was associated a few years ago, as research chemist and pilot plant operator with the Werner G. Smith Co. (div. of Archer, Daniels, Midland Co.), Wyandotte, Mich.

Anthony P. Massa has been appointed a research assistant at the Polytechnic Institute of Brooklyn having obtained a leave of absence from the H. K. Ferguson Co., New York, where he was employed as a design engineer. He will continue graduate studies at the Institute leading to the doctor's degree in chemical engineering. The research under the assistantship is sponsored by the Research Committee of A.I.Ch.E. and is concerned with plate efficiencies in fractionating towers.

J. Kelly Dixon, formerly special products representative in Houston, of Shell Oil Co., has been appointed to succeed D. W. Nolf, as manager, special products department, in the St. Louis Division.

BARR, SENIOR ENGINEERING ASSOCIATE

Frank T. Barr has been named a senior engineering associate by the Standard Oil Development Co., Linden, N. J., in accordance with the company's policy of recognizing "outstanding technical contributions of the individual members of its staff."

Dr. Barr did his undergraduate work at Washington University and received his doctorate from the University of Illinois. After a short period of teaching at the Armour Institute of Technology, he joined the research and development department of the Standard Oil Company of Louisiana. In 1936, he was transferred to the Standard Oil Development Co. as chemical engineer in development division.

CURTIS IN ST. LOUIS OFFICE OF MONSANTO

Francis J. Curtis, vice-president and director of Monsanto Chemical Co., who has been director of Monsanto's industrial preparedness at Washington, D. C., has transferred to the company's headquarters in St. Louis and will devote full time to handling special assignments for Charles Allen Thomas, president. He will report directly to the president.

Mr. Curtis, a former President of A.I.Ch.E., and at present president of the Society of Chemical Industry, has been with Monsanto since 1915.

Bruce Jones has assumed an executive position with Panhandle Oil Corp., Wichita Falls, Tex. In this position he will develop research and plan activities for the refining and marketing division. Mr. Jones was formerly chief project engineer of the fats and oils section of the Girdler Corp., Louisville, Ky. Before going with Girdler in 1947, he was associated with the Texas Co. where he served in several technical capacities for about seven years. He was graduated from the University of Texas in 1940 with an M.S. in chemical engineering.

George M. Machwart, the first recipient under the Monsanto Chemical Co.'s reactivated "experience-on-the-job" program, has returned to his former position as professor of chemical engineering at Michigan College of Mining and Technology after a year in the phosphate division of Monsanto at Anniston, Ala.

HOUSTON CONSULTING GROUP ORGANIZES

The formation of a new consulting chemical and petroleum engineering partnership, Prengle, Dukler & Crump, has been announced. The group was formed by H. W. Prengle, Jr., A. E. Dukler, and J. R. Crump. Messrs. Prengle and Dukler are members of A.I.Ch.E.

A. E. Dukler received a B.E. degree from Yale University, and an M.E. and Ph.D. degree in chemical engineering from the University of Delaware. Dr. Dukler worked for the Rohm & Haas Co. of Philadelphia as a process engineer, and for the Shell Oil Co., Houston refinery, as research engineer. During his employment with Shell he worked on catalytic and thermal cracking, catalyst deactivation studies, and lube oil processing.

H. W. Prengle, Jr., received a B.S., M.S., and D.Sc. in chemical engineering from Carnegie Institute of Technology. During World War II he served in the Army Corps of Engineers as Lt. Colonel. Dr. Prengle worked for the Linde Air Products Co. of Tonawanda, N. Y., as research engineer, and for the Shell Oil Co., Houston refinery, as senior research engineer, group leader, and senior technologist. During his employment with Shell he worked in the lubricating oils and cracking departments.

Kenneth T. Barker, who has been handling chemical engineering plant design for DeBell & Richardson, Inc., has transferred as chief engineer to Shore Line Industries of Clinton, Conn.

William F. Gerrow, Jr., field sales representative of Goodyear Tire & Rubber Company's chemical division, who has been in training at the division's district office in Atlanta, Ga., has been assigned permanently to that location.

Gerrow served in the United States Army infantry from 1943 to 1946. In 1947 he earned a B.S. in chemical engineering at Drexel Institute of Technology, Pihladelphia. Two years later he received an M.S. at the Institute of Textile Technology, Charlottesville, Va., where his fundamental work was a study of the physical chemistry of fibers. From 1949 until he joined Goodyear in May this year, he was laboratory manager of Fulton Bag & Cotton Mills, Atlanta.

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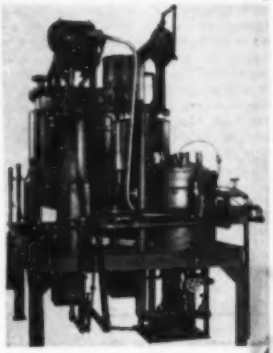

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CLASSIFIED SECTION

Advertisements in the Classified Section of Chemical Engineering Progress are payable in advance, and are placed at 15c a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line insertion (about 36 words) free of charge per year. More than one insertion to members will be made at half rates. In using the Classified Section of Chemical Engineering Progress it is agreed by prospective employers and employees that all communications will be acknowledged, and the service is made available on that condition. Boxed advertisements are available at $15 per inch. Size of type may be specified by advertiser. In answering advertisements all box numbers should be addressed care of Chemical Engineering Progress, Classified Section, 120 East 41st Street, New York 17, N. Y. Telephone ORegon 9-1560. Advertisements for this section should be in the editorial offices the 15th of the month preceding the issue in which it is to appear.

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Chemical engineers with three or more years of experience in process design and engineering, preferably in petroleum refining. Should be capable of assuming responsibility for the design of major refining units and auxiliaries.

Also require several chemical engineers of less experience for training in petroleum process engineering.

Replies should give experience, education, technical references and salary requirements.

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ANALYST—At least two to three years' experience preferred; chemistry, physics or metallurgy background; to conduct chemical and spectroscopic analysis and mineral assay. Start as assistant analyst for training to become chief analyst in about a year. This is a permanent position with twelve-month appointment on the staff of the school. Salary commensurate with experience and training. Apply to: Associate Director, Engineering and Mining Experiment Station, School of Mines and Technology, Rapid City, South Dakota.

CHEMICAL ENGINEERING TEACHER — Wanted by accredited Midwestern university. Ph.D. desirable but not mandatory. Salary and rank dependent on previous experience. Opportunity for both teaching and research. Send résumé to Box 1-11, Chemical Engineering Progress, New York, New York.

CONNECTION AS SALES REPRESENTATIVE for manufacturer of refinery or chemical plant equipment desired by small consulting engineering firm in California. Box 4-11.

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Leading scientific manufacturer is expanding technical sales force as part of long-range growth program. Technically trained young men with sales qualifications will find very attractive career opportunity to sell instruments for industrial process and research use. Comprehensive factory training on products and salesmanship. Good starting salary plus incentive pay when qualified.

Applicant should have college degree, or equivalent, with a major or minor in chemistry, physics or engineering. Sales experience desirable but not essential. Send complete résumé, including age, marital status, work experience, college technical courses and salary requirements.

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Our Employees Know of this Advertisement

REPLY TO BOX NO. 35-11

EASTERN CONSULTING ENGINEERING FIRM specializing in industrial water procurement, treatment, and control has openings on its staff for young chemical engineers or chemists, recent graduates, 1948 or later. Positions involve traveling as field engineers. Experience in industrial water treatment or steam and power plant operation helpful but not necessary. Salary open. Box 3-11.

SITUATIONS WANTED

A.I.Ch.E. Members

ACADEMIC POSITION—Chemical Engineering Ph.D. Age 34, family. Active member A.I.Ch.E. Seek teaching position with responsibility and opportunity. Twelve-month basis preferred. 7½ years' teaching, industrial, and consulting experience. Publications. Excellent references. Available February or June, 1953. Box 2-11.

CHEMICAL ENGINEER—Single, 25. One year experience. Desire to relocate permanently in California or Texas. Good fundamental background. Starting salary secondary if advancement opportunities good. Chemical or petroleum industry preferred. Will travel. Available immediately. Box 5-11.

CHEMICAL ENGINEER — MANAGEMENT — Cornell, 1943, Alexander Hamilton Institute. One employer since graduation. Manager research and development department four years; have been credit manager, sales engineer, pilot-plant supervisor, petroleum refinery engineer, chemical operator, etc. Present salary $11,000. Age 33, married, three children. Interested in large stable company or growing small company with incentive arrangemnet. Outstanding references. Box 6-11.

CHEMICAL ENGINEER—B.Ch.E. Age 29. Desire challenging position in North Eastern location. 4½ years' experience in producing bulk organic chemicals, supervisory and design experience including personnel management and safety aspects. Box 7-11.

CHEMICAL ENGINEER—B.Ch.E. 1950. Diversified experience in pulp and paper manufacture. Converting. Waste treatment; water treatment; process control; production. Presently in supervisory position. Wish position with future. Veteran. Single. Box 8-11.

BRIGHT YOUNG MAN desires position with design engineering group which will provide opportunity for advancement through hard work. M.S.Ch.E. Single, veteran, 27 years old. 1½ years' process development experience. Box 9-11.

SALES ENGINEER—B.S. chemical engineering, 1947, Alexander Hamilton Institute. 3½ years' refinery and 1½ years' sales experience with major oil company in Midwest. Age 27, married, and family. Desire responsible sales or engineering position. Box 10-11.

CHEMICAL ENGINEER—35. B.Ch.E., postgraduate work, family. Extensive experience process development and engineering: pilot plant design and operation; equipment design, instrumentation, and layout; process trouble shooting; economic evaluations; thermodynamic calculations; laboratory research. Seek responsible position engineering or development. Box 11-11.

CHEMICAL ENGINEER OR DEVELOPMENT EXECUTIVE—M.I.T. graduate. Outstanding record for cost reductions through improving existing operations and/or development of new processes. Wide experience in basic industries. Outstanding references including present employers'. Interested in position of responsibility with permanent future and requisite authority to give results. Box 12-11.

DESIGN ENGINEERING position desired by chemical engineer with Master's degree. 1½ years' experience in research, process development. Veteran, single, 27. Northeastern U. S. preferred. Box 13-11.

CHEMICAL ENGINEER—B.S.Ch.E. (1951). Age 23. Deferment until March, 1953. 1½ years' experience as production supervisor in large pharmaceutical firm. Desire position in production or development with firm which will ask for continued deferment. Box 14-11.

CHEMICAL ENGINEER—Twelve years' excellent diversified industrial experience. Organic, pharmaceutical, and fermentation manufacturing. Used to quick start up and improvisations. Firm understanding of equipment, maintenance, trouble shooting, economics, personnel and administration. Age 35, married, family. Box 15-11.

CHEMICAL ENGINEER—M.S. 1950. Age 28. Experience in production supervision, staff chemical engineering, and industrial engineering. Extensive background in vacuum distillation, electronics, and quality control. Desire production assignment in Western U. S. Available Spring, 1953. Box 16-11.

CHEMICAL ENGINEER—D.Ch.E., P.E. Well grounded in chemistry, mathematics, physics. Four years process development in electrochemistry, corrosion, metallurgy and metal finishing. Three years development in atomic energy and radiology. Desire research and development opportunity in greater New York City area. Box 17-11.

CHEMICAL ENGINEER—B.Ch.E. Age 33. World War II veteran, married. Interested in laboratory position, any field. Six years' experience in dye industry. Will re-establish residence. Available March 31, 1953. At present employed as aircraft mechanic 1/C U.S.N. Box 18-11.

CHEMICAL ENGINEER—M.S. Fifteen months' experience in process development. 27, single, veteran. Desire position which will provide opportunity for some design engineering work. Box 19-11.

B.Ch.E. (1943)—30, family. Nine years' experience in research, pilot plant supervision and operation, process design and cost estimation, and quality control with organic silicone intermediates. Available immediately for responsible position. Box 20-11.

PEOPLE

(*Continued from page 77*)

NANTZ, VITTONE IN NEW JOBS WITH GOODRICH

Tom B. Nantz has been named manager of B. F. Goodrich Chemical Co.'s new vinyl plastic monomer plant now in its final construction stages at Calvert City, Ky. The move was effective Nov. 1. Anton Vittone, Jr., will take over Nantz' former duties as plant manager at Institute, W. Va. GR-S rubber plant, operated for the Government by B. F. Goodrich Chemical Co. Vittone is now plant engineer at Institute.

Nantz went to work in B. F. Goodrich laboratories as a chemist shortly after being graduated in 1937 from the University of Kentucky with a B.S. in industrial chemistry. In 1940 he became a foreman and technical man in one of the company's Akron plants. During early World War II he served as technical service manager of the Lone Star Defense Corp., Texarkana, Tex., which was operated for the Government by B. F. Goodrich. He was transferred to the Louisville GR-S plant in 1943, later became production manager until the plant closed in 1946. Nantz served as production manager of B.F.G.'s Chem. Hycar nitrile rubber plant in Louisville from 1947 until 1950, when he was sent to reactivate the Government-owned plant at Institute.

Vittone joined B. F. Goodrich in 1942 as a GR-S shift foreman, became general foreman in Louisville, and in 1947 was transferred to the Geon polyvinyl chloride plastic resin plant in the same city as a general foreman. He went to England in 1949 to assist in the construction and initial operation of British Geon, Ltd., an affiliate of B. F. Goodrich Chemical, and in the same year returned to Louisville. He was then sent to Institute, W. Va., in 1950 as production manager of the world's largest rubber plant. A year later he became plant engineer. Vittone was graduated from the University of Washington with a B.S. in chemical engineering, and received his M.S. in chemical engineering from the same university in 1939.

Robert S. Casey, director of research of the W. A. Sheaffer Pen Co., Fort Madison, Iowa, has been elected chairman of the American Chemical Society's Division of Chemical Literature for 1953.

Mr. Casey received the B.S. degree in 1919 from Trinity College in Hartford, Conn., and the M.S. in 1920. After a year's graduate study at Columbia University, he joined the Sheaffer company as a chemist in 1921. He became chemist and manager of the company's Scrip factory in 1922 and was named to his present post in 1943.

Sherwood B. Seeley has been advanced to the position of technical director of the Joseph Dixon Crucible Co., Jersey City, N. J. Mr. Seeley, for the past eight years director of research, will exercise direct control of the laboratories, research, development and engineering activities of the company. Mr. Seeley joined the firm in 1930. He is a chemical engineer, and a graduate of New York University.

D. P. Barrett, formerly in charge of the Davison Chemical Corp.'s New York sales office, has been appointed assistant general sales manager of the corporation's industrial chemical department. Mr. Barrett, a Princeton graduate in chemical engineering, joined Davison in 1946 after a service period as a naval aviation pilot.

W. R. Seuren has been, since last spring, industrial sales representative for Deep Rock Oil Corp. for North Central United States and Canada. The company's industrial petroleum products include solvents, naphthas, waxes, etc. Before assuming his present duties he was lube finishing supervisor at Deep Rock's Cushing, Okla., refinery. In his present position Seuren works out of the Chicago offices.

H. D. Guthrie, formerly with the Shell Development Co., Emeryville, Calif., is now with the Shell Oil Co. at Wood River, Ill.

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Thomas A. Matthews II has accepted a position with the chemical engineering department of The Western Co., Midland, Tex., effective Nov. 1, 1952. Mr. Matthews will be engaged in field service and research in connection with acidizing, perforating, and logging of wells.

After graduating from Northwestern Technological Institute in 1946, Mr. Matthews spent nearly six years in the research and development laboratories of the Pure Oil Co. He was located in Crystal Lake, Ill., and held the title of research engineer. Mr. Matthews held the position of Public Relations Chairman for the Chicago Section of the American Institute of Chemical Engineers for the 1951-1952 season.

Emerson J. Lyons has been appointed general manager of the turbo-mixer division of the General American Transportation Corp. Mr. Lyons has offices at 10 East 49th Street, New York City.

Robert Kirk, of Norwalk, Conn., export manager for the past six years for the chemical division of McKesson & Robbins, Inc., has been appointed manager of the newly formed foreign department of the Pittsburgh Coke & Chemical Co. This department will direct all the company's overseas chemical sales operations. Headquarters of the new department will be in the Empire State Building, New York. Mr. Kirk, a graduate of Lemania College, Switzerland, attended the school of engineering at the University of Lausanne, Switzerland. He brings to his new post experience in chemical process development gained during five years' association with Merck & Co., Inc.

E. G. Foster has joined the staff of Shell Development Co., Emeryville, Calif. Foster goes to Shell from the University of Louisville, where he was assistant professor of chemical engineering.

B. E. McNay has been appointed senior project engineer by the Rucker Co., Oakland, Calif. Mr. McNay is a graduate of the University of Washington, receiving a degree in chemical engineering in 1935. His experience includes chemical plant and equipment design, process development, research, development and plant management.

Jerome Wilkenfeld has been appointed supervisor of process study of Hooker Electrochemical Co. He has been associated with the company since 1943. Mr. Wilkenfeld was graduated from City College of New York as a chemical engineer. He has been employed in various departments, being transferred to the process study group in 1945. Prior to his recent promotion he was a group leader.

Guy J. Walker and **Basil J. Reitzer** are recent additions to the research staff of Standard Oil Company (Indiana) at Whiting. Mr. Walker did his undergraduate work at Iowa State College and obtained his M.S. degree in chemical engineering at Newark College of Engineering. Dr. Reitzer obtained his Ph.D. degree in chemical engineering at Northwestern University, where he also did his undergraduate work.

G. L. Pitzer, formerly assistant superintendent, Carbide and Carbon Chemicals Co., Texas City, Tex., is now works manager, Bakelite Co., New York.

Necrology

G. J. ESSELEN

Gustavus J. Esselen, vice-president of the U. S. Testing Co., Inc., in charge of Esselen research division, Boston, Mass., died Oct. 22. A Ph.D. from Harvard University, Dr. Esselen started on his career, after a short teaching period at Harvard, in the research laboratory of the General Electric Co., Lynn, Mass., and for many years was actively engaged in several enterprises including the Chemical Products Co., Arthur D. Little, Inc., Skinner, Sherman & Esselen, Inc., becoming in 1930 president of Gustavus J. Esselen, Inc. In 1946, he founded the Esselen Research Corp. in Boston which merged three years later with the United States Testing Co.

He was no less active in A.I.Ch.E. affairs: he was named a candidate for President in 1941, and served as Director, 1931-1933 and 1934-1936; a member of several committees including the Technological Unemployment, Local Membership, Papers, and Trade Waste Disposal.

World affairs also occupied his attention. He was consultant to the Baruch Rubber Survey Committee in 1942; during World War II he served as a member of the chemical referee board of the W.P.B. and as a committee chairman of the Joint Army-Navy Office of Scientific Research and Development Board.

Dr. Esselen was 64 years old.

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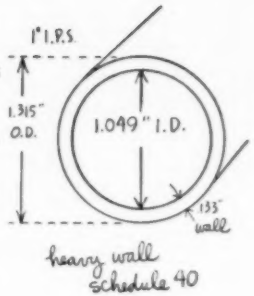

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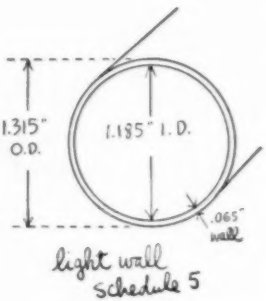

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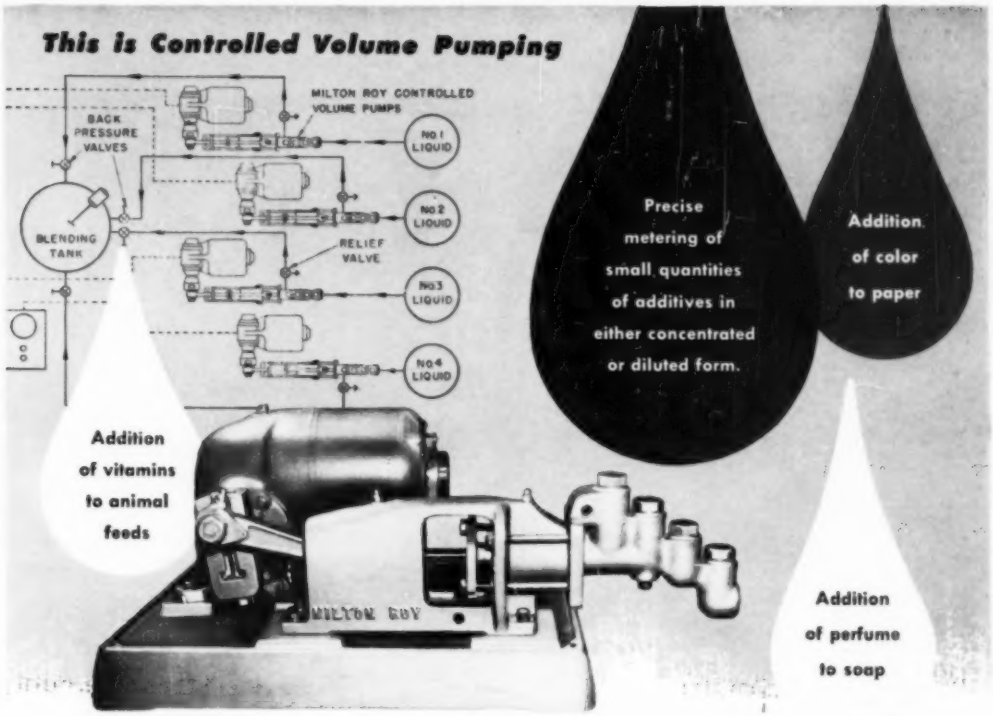
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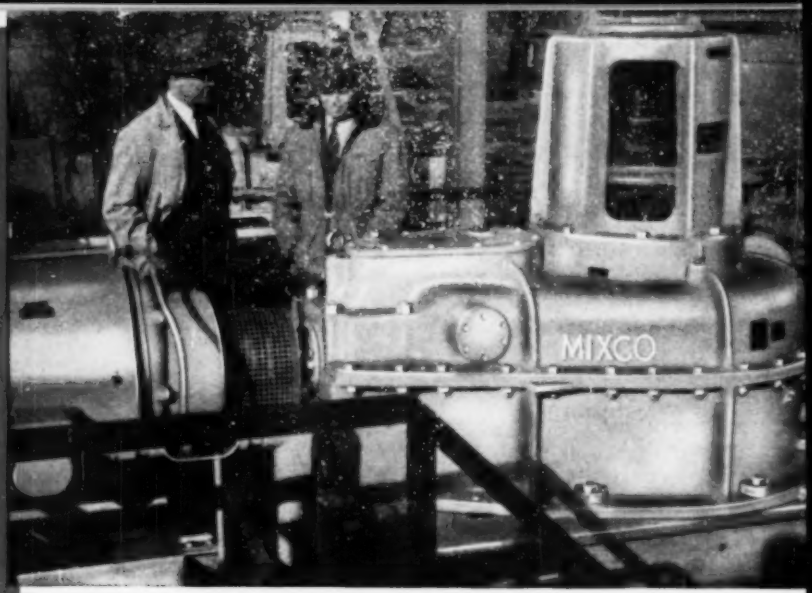

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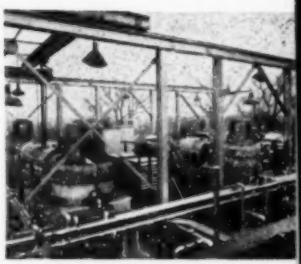

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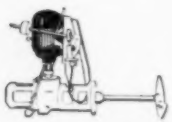

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